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HARVARD ENGINEERING JOURNAL

DEVOTED TO THE INTERESTS OF
ENGINEERING AND ARCHITECTURE
AT HARVARD UNIVERSITY

Vol. I

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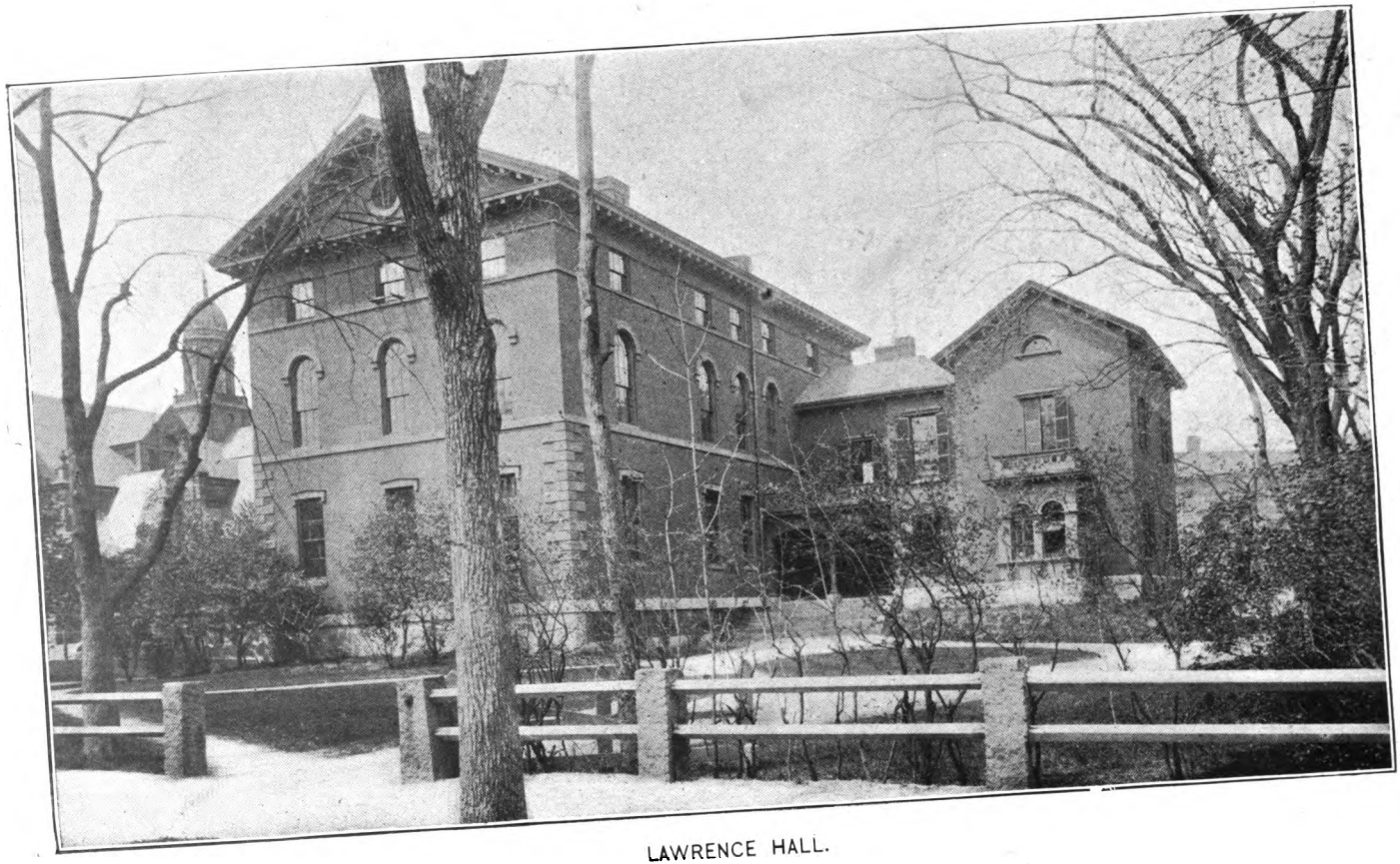
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HARVARD ENGINEERING JOURNAL

Devoted to the interests of Engineering and Architecture at Harvard University

PUBLISHED BY THE HARVARD ENGINEERING SOCIETY

VOL. I APRIL, 1902 NO. 1

A HISTORY OF ENGINEERING AT HARVARD UNIVERSITY.

JAMES LEE LOVE, p. '90.

Assistant Professor of Mathematics and Secretary of the Lawrence Scientific School.

THIS paper has been prepared at the request of the Editors of the HARVARD ENGINEERING JOURNAL. It aims to present in detail a sketch of engineering instruction at Harvard University, and to give some account of the origin and progress of the Lawrence Scientific School in which this instruction has been given.

For some years prior to 1847, the need had been felt in New England for instruction of a more advanced character than was possible under the prescribed curriculum of the College of that period. It had begun to appear that the provision for teaching science was totally inadequate; and that, if society were not to suffer serious consequences, something had to be done to furnish suitable technical training for young men who proposed to serve the community in the several professions depending on a knowledge of exact science. It was evident, also, that opportunities should be offered to young men who intended to engage in teaching, — particularly to those who looked forward to college work, — whereby they could do graduate work in their chosen specialty.

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An earnest expounder of these views was the Hon. Samuel A. Eliot, '17, of Boston, then Treasurer of Harvard College. His annual reports show that he was keenly alive to these pressing needs. They were pressing because it was a time when growing manufacturing industries, when the opening of mines, when the expansion of the country, and when the development of railways with their attendant surveying and mechanical problems, all demanded men trained in science. One school had been organized at Troy, N. Y., as early as 1824, to meet these demands. Sagacious men at Harvard thought that the time had come for them to act. Hence it came about that, in February, 1847, during the term of President Edward Everett, '11, the governing boards of Harvard University approved a plan for establishing an "Advanced School of Science and Literature," to be called "The Scientific School of the University at Cambridge." The declared aim was to provide instruction for "graduates and others in the various branches of exact and physical science, and in classical learning." The scientific subjects named in the first announcement of the School, in the University catalogue of 1847–48, were "mathematics; astronomy, theoretical and practical; chemistry, in its various branches, theoretical and operative; civil engineering, and generally the application of science to the arts of life and the great industrial interests of the community; with the several branches of Natural Science." The classical department was to be "mainly devoted to those studies which form the preparation for academic life": but instruction in "classical learning" was never organized in the School.

"All graduates of the University, or of any other collegiate institution," and all other persons of suitable age and qualifications, were admissible to the School. It will thus be seen that the Scientific School was, in its purpose, the forerunner of the Graduate School. It was, apparently, the first graduate school established by any college in this country.

The Corporation had no funds with which to carry out the plan; being dependent upon the voluntary services of professors already engaged, and upon the accumulated resources of the

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University. The first provision for instruction appears to have been the appropriation of the Rumford bequest for a chair of chemistry, and the election of Eben Norton Horsford to the Rumford professorship. No further provision for instruction could be made with the means controlled by the Corporation.

At this juncture the Corporation received from the Hon. Abbott Lawrence the letter which is quoted, in part, below.

TO THE HON. SAMUEL A. ELIOT, TREASURER OF HARVARD COLLEGE.

"Boston, June 7th, 1847.

"*My dear Sir:*

"I have more than once conversed with you upon the subject "of establishing a school for the purpose of teaching the practi- "cal sciences, in this city, or neighborhood; and was gratified "when I learned from you that the government of Harvard "University had determined to establish such a school in Cam- "bridge.....

"For several years I have seen and felt the pressing want in "our community (and, in fact, in the whole country) of an "increased number of men educated in the practical sciences. "Elementary education appears to be well provided for in "Massachusetts. There is, however, a deficiency in the means "for higher education in certain branches of knowledge. For "an early classical education we have our schools and colleges. "From thence the special schools of theology, law, medicine, "and surgery receive the young men destined to those profes- "sions; and those who look to commerce as their employment "pass to the counting house or the ocean. But where can we "send those who intend to devote themselves to the practical "applications of science? How educate our engineers, our "miners, machinists, and mechanics? Our country abounds in "men of action. Hard hands are ready to work upon our hard "materials; and where shall sagacious heads be taught to "direct those hands?....

"I believe the time has arrived when we should make an effort "to diversify the occupations of our people, and develop more

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"fully their strong mental and physical resources, throughout "the Union.....

"We need, then, a school, not for boys, but for young men "whose early education is completed, either in college or else- "where; and who intend to enter upon an active life as engineers "or chemists, or, in general, as men of science, applying their "attainments to practical purposes.....

"I have thought that the three great practical branches to "which a scientific education is to be applied amongst us are, "1st, Engineering; 2nd, Mining, in its extended sense, includ- "ing Metallurgy; 3rd, The invention and manufacture of "machinery. These must be deemed kindred branches, starting "from the same point, depending in many respects on the same "principles, and gradually diverging to their more special "applications.

"I therefore propose to offer, through you, for the acceptance "of the President and Fellows of Harvard College, the sum of "fifty thousand dollars, to be appropriated as I have indicated "in the foregoing remarks.....

"I beg to suggest, further, that the whole income of this "School be devoted to the acquisition, illustration, and dissemin- "ation of the practical sciences forever.

(Signed) ABBOTT LAWRENCE.

Mr. Lawrence supposed that a suitable building could be erected for $30,000; and he suggested that the remaining $20,000 should form the basis of a fund to be devoted to sustaining the professorships of engineering and geology.

Mr. Lawrence's gift was said to have been unprecedented in amount, as a single gift to education bestowed during the lifetime of the donor. In recognition of it the Corporation and Board of Overseers voted, at the commencement in June, 1847, to designate the new school as "The Lawrence Scientific School in the University at Cambridge."

Mr. Lawrence's interest in the School never wearied. When

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negotiations for a professor of engineering were about to fail for lack of money, he stepped forward and guaranteed a stated sum for a term of years, and secured the professor. He aided with wise counsel as well; and, at his death in 1855, he bequeathed a second $50,000 to the School.

Instruction in chemistry was begun in 1847, by Professor Horsford, in temporary quarters in University Hall: and in the same year Louis Agassiz was chosen Professor of Zoology and Geology; but he did not begin teaching, it seems, until 1848.

Lawrence Hall was built in 1848. It was devoted wholly to the uses of the chemistry department. It contained the laboratories, libraries, store-rooms, etc., of Professor Horsford; and the east wing of the building was occupied as a dwelling by his family. As a chemical laboratory it was "understood to be "one of the best constructed and most amply furnished in the "world."

The courses in engineering were delayed in opening, unfortunately, on account of the difficulty in finding an engineer of suitable training willing to give up the practice of his profession for the sake of teaching.

The departments of engineering and geology were less fortunate in securing laboratories than the chemistry department had been. Mr. Lawrence did not carry out what seems to have been his intention of housing them in a building comparable with the one built for Professor Horsford. His uncompleted plan contemplated a central structure lying east and west, with a west wing to be a counterpart of the present Lawrence Hall, which was to be the east wing.

Henry Lawrence Eustis, '38, was chosen Professor of Engineering in 1849. He began his instruction in March, 1850, with nine students. He shared with Professor Agassiz a new plain, two-story, wooden building, erected, apparently, by the University on a part of the site covered by the Hemenway Gymnasium. This building, after four removes, now stands next the Rotch building on Holmes Field. (The engineering department, the Agassiz museum, and the department of architecture began their careers in this building, which was formerly

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called Zoological Hall.) Professor Agassiz's lecture room and zoological collections occupied the second story. Professor Eustis's lecture room and drawing room were on the ground floor. The laboratory equipment of the latter consisted "solely of blackboards, drawing tables, and a case of surveying instruments."

The instruction in engineering, and the material equipment necessary therefor, gave the new Professor much care. His work was that of a pioneer. An ex-President of the University advised him to "open an office as a surveyor and receive young "men into his office" as assistants or apprentices, — advice which he did not accept. The plan of instruction adopted was largely experimental; and is indicated in the following announcement which appeared for the first time in the University catalogue for 1850–51: —

"Professor Eustis will receive special students to the course "of instruction in engineering, who will give their attendance "at the School from 9 o'clock A. M. to 5 o'clock P. M.

"The course will include instruction in —

"Descriptive geometry, with its applications to masonry and "stone-cutting, the construction of arches, &c.

"The theory of shades, shadows, and perspective, illustrated "by a course of drawing, and mapping in all its branches.

"Surveying, with the use of instruments, and actual opera- "tions in the field.

"The nature and properties of building materials, and their "applications to the construction of railroads, canals, bridges, &c.

"For those who are not sufficiently prepared, the course will "commence with a review of such parts of practical mathematics "as may be required."

The last provision turned out to be very necessary. The Professor found his burden heavy on account of the diversity in the preparation of his students; and he was obliged to teach them in small sections, classified according to their progress. Some candidates had to be rejected for lack of the necessary qualifications.

The admission requirements stated that candidates "must "have received a good common English education, and must be

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"qualified to pursue to advantage the chosen courses of study." No admission examination seems to have been set, other than an oral inquiry by the professor. Students were at liberty to choose both the number and kind of studies to be pursued, under counsel from the Professor. Attendance on lectures and recitations was voluntary; and the government of the University "discouraged" the resort to the School of young men "who do "not, in the opinion of their parents, or guardians, possess that "stability of character and firmness of purpose which will ensure "a faithful performance of duty, without academic discipline." Voluntary attendance appears to have been adopted because the authorities expected graduate students, and maturer persons only, to attend the School.

In the department of engineering, fees were charged, curiously, as follows: "For instruction six days in the week, fifty "dollars per term. For three days in the week, two-thirds, and "for one day, one-third, of the above sum." This method of charging for tuition was abandoned in 1863.

Students were required to supply themselves with conveniences for drawing, necessary text-books, etc.

Members of other schools of the University were permitted to attend the lectures on payment of a suitable fee per course.

The work of the Scientific School was, from the beginning, and until 1890, under the immediate charge of a separate Faculty, which was "only a large committee of the College Faculty." Professor Horsford was the first Dean of the Scientific Faculty.

The degree of Bachelor of Science was instituted in 1851; and the first students in engineering to receive this degree were Gustavus Hay, Richmond Jones, J. Smith Homans, and Charles Person, in July, 1853.

The candidate for this degree was required to pass "a full "and satisfactory examination in the studies of one or more "departments," and to attend "the instruction in the School for "at least one year." The amount of study requisite for the degree was decided by the Faculty of the School, subject to the approval of the Corporation.

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The original outline of the courses was somewhat modified for the catalogue of 1851–52, and was as follows: —

"Surveying, etc., as before.
"Drawing in all its branches; topographical, outline, shaded, "and tinted, including isometric projections.
"Analytical geometry; differential and integral calculus.
"The principles of mechanics and their applications to machin- "ery and engineering.
"Descriptive geometry.
"The theory of shades, shadows, and perspective.
"The applications of descriptive geometry to masonry and "stone-cutting, and in the construction of groined and cloistered "arches, domes, etc.
"The nature and properties of building materials, etc., as in "1850–51.
"The instruction will be given by daily exercises at the "blackboard and by lectures."

In 1853, the following statement was added to this outline: "Knowledge of algebra, geometry and trigonometry is required "before admission."

The foregoing announcement appeared with practically no change from 1851 to 1871. During years when the departments of chemistry, botany, astronomy and geology were growing into strong and important branches of the University, the authorities appeared unable to take advantage of the opportunities in engineering; and did not seem to understand their first announcement of engineering as "the application of science "to the arts of life and to the great industrial interests of the community." This view of engineering involves the coordination of subjects selected from all the sciences. It embraces a comprehensive course of studies, combined with enough laboratory practice to enable the student to grasp their significance in the arts. No engineering laboratory was established until 1892.

In 1855 the principle of voluntary attendance on class-room exercises was abandoned, and the students were henceforth required to give "punctual attendance on all prescribed courses."

In 1864 the University catalogue announced for the first

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time that: "Candidates for the courses in engineering will be "examined in Sherwin's algebra, and Legendre's geometry and plane trigonometry, or their equivalents." No specific admission requirements for the courses in chemistry and geology were announced up to this time, nor for some years after.

During the years 1862–63 and 1863–64, Professor Eustis was absent on service in the Civil War. He entered the army as Colonel in the Tenth Massachusetts Volunteers, and resigned in 1864 with the rank of Brigadier-General. During a portion of the time of his absence, his courses were under the charge of Charles W. Eliot, Assistant Professor of chemistry and Acting Dean of the Faculty of the Lawrence Scientific School; but the instruction was given by Mr. Edward Pearce, A. B. 1853.

In 1870 the degree of "Civil Engineer" was instituted to replace the degree of "Bachelor of Science for Civil Engineers." But the degree of "Bachelor of Science" was restored in 1888, and has since then been the sole degree of the Scientific School.

From 1851 to 1870 the University catalogue announced that the degree of the School would be conferred on "any student "who, having attended the instruction of the School for at least "one year, and completed the prescribed course of studies in one "or more departments, shall have passed a satisfactory public "examination." It was common to take the degree after two years of resident study. Some candidates won it in one year — others in three and four years. The student of engineering was expected to work daily from 9 A. M. to 5 P. M. in the rooms of the department, under the direction of the professor; but the amount of work was optional, although the selection of courses was made with the advice of Professor Eustis. Until 1871 students of engineering were called "special students" in the University catalogue; although many of them were candidates for the degree of the School.

With the inauguration of President Eliot in 1869, a change began to be apparent in the attitude of the University toward the Scientific School and engineering. In his report for 1870–1871 President Eliot says: "Plans for the reorganization of the "Lawrence Scientific School were actively discussed during

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"the spring of 1871. The objects in view were to lengthen "the term of residence in the department of engineering, "and to enlarge the course of instruction in that subject; ".... These objects have been effected by the plan which "went into operation at the opening of the year 1871–72. A "very thorough four years' course of study is now provided for "young men who wish to be well trained in the profession of "civil and topographical engineering. To increase the amount "of instruction in field work and drawing the professorship of "topographical engineering was established and filled."

The professor of civil and topographical engineering was Charles Frederick Hoffman; who resigned after one year of service, attracted to California by the larger rewards offered in the practice of his profession.

The remodeled course was thus announced in the University catalogue of 1871–72: —

"A four years' course of study in Civil and Topographical "Engineering as follows:

"*First Year* — Spherical trigonometry; analytical geometry; "descriptive geometry; chemistry; surveying and plotting; "road-making; freehand and water-color drawing; French.

"*Second Year* — Differential and integral calculus; mechan- "ics; physics; mathematics and physical geography; elemen- "tary geology; crystallography; mineralogy, and the use of "the blow-pipe; mechanical drawing; French and German.

"*Third Year* — Applied mechanics; practical astronomy and "geodesy; hypsometry; topographical surveying and draw- "ing; higher structural geology; palæontology; photography; "and German.

"*Fourth Year* — Building materials, and their application in "railroads, canals, bridges, etc.; applications of descriptive "geometry to masonry and stone-cutting; hydraulics; heat "and its applications; discussions of existing structures and "the working out of projects."

Candidates for admission to this programme were required to be examined in arithmetic, algebra, geometry, and trigonometry. Graduates of colleges were exempt from additional examinations, and were allowed to enter in advanced standing. Students who completed this course satisfactorily received the

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degree of Civil Engineer, and were "prepared to enter on the practice of their profession."

The next problem before the authorities of the School in 1871 was: raising the standard of admission. Hitherto, candidates for the course in engineering had been required to show only "a certain degree of proficiency in elementary mathematics." In 1873–74 a new plan of admission examinations was announced; and in the examinations of 1874 candidates were required to pass examinations in geography, English composition, Latin, French or German, arithmetic, algebra, plane and solid geometry, and plane and analytical trigonometry. This step, together with that of establishing the four years' course, was taken "to secure better trained students"; to make the degree in science "as well worth having" as the degree in arts; and in order "to secure more satisfactory relations with the preparatory schools."

Physical geography was dropped from the admission requirements in 1876; physics and chemistry were added in 1878.

Arrangements were made in 1871 to facilitate the transfer of graduates of Harvard College to the course in engineering. The successful study of any subject in Harvard College was accepted as an equivalent for the same subject in the Scientific School. By this means College graduates were able, by properly choosing their undergraduate courses, to enter the third year of the engineering course.

The work of the first three years of the course in engineering was accepted in the "School of Mining and Practical Geology" as the first three years' work in that school from candidates for the degree of *Mining Engineer*. This "School of Mining and Practical Geology" was established in 1865, and given up in 1875. Wolcott Gibbs was its Dean until 1868, and Josiah Dwight Whitney from 1868 to 1875.

In 1878–79 the Faculty of the Scientific School revised the course of study in engineering "with the intent of reducing the "amount of daily work demanded of the students, which had "proved to be excessive." A few changes had been made since the reorganization in 1871. In 1878 the outline of courses stood as follows:—

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"*First Year* — Spherical trigonometry and analytical geom-
"etry; descriptive geometry and perspective; elementary
"physics; elementary chemistry; freehand and water-color
"drawing; surveying, plotting, and topographical drawing;
"mechanical drawing; and French.

"*Second Year* — Differential and integral calculus; elemen-
"tary physics; elementary chemistry; French; German;
"mechanical drawing; levelling and topographical drawing;
"and Henck's Field Book.

"*Third Year* — Mechanics; experimental physics; deter-
"minative mineralogy and lithology; physical geography;
"meteorology; and structural geology; German prose; and
"mechanical drawing.

"*Fourth Year* — Applied mechanics and constructive engi-
"neering; applications of descriptive geometry to masonry and
"stone-cutting; heat and its applications; economic geology;
"practical astronomy and geodesy."

During the first year the students devoted thirteen hours a week to lectures, and seventeen hours to drawing and laboratory work; during the second year, fourteen hours to lectures, and fifteen to drawing and laboratory; during the third year, twelve hours to lectures, and seven to drawing and laboratory; during the fourth year, thirteen hours to lectures, and a number of hours, not stated, to the work in the applications of descriptive geometry and in the preparation of a thesis.

The school had lately been losing students in several ways. President Eliot said in his report for 1878–79: "The institu-
"tion, in 1872, of the degrees of Doctor of Philosophy and
"Doctor of Science, under the charge of the Academic Council,
"deprived the Scientific School of a small class of advanced
"students, who formerly gave it dignity (and) the
"long continued depression in the industries which demand
"engineering and chemical skill, has reduced the number of
"students preparing themselves for the scientific professions."

The changes made in 1878–79 left the four years' course in Civil and Topographical Engineering as follows:—

"*First Year* — Spherical trigonometry and analytical geom-
"etry; descriptive geometry and perspective; elementary

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"physics; surveying, plotting, and topographical drawing; "and mechanical drawing.

"*Second Year* — Differential and integral calculus; elemen- "tary physics; elementary chemistry; German or French; "mechanical drawing; levelling, topographical drawing; and "Henck's Field Book.

"*Third Year* — Mechanics; French; German scientific "prose; mechanical drawing; freehand and water-color draw- "ing.

"*Fourth Year* — Applied mechanics, and constructive engi- "neering; applications of descriptive geometry to masonry "and stone-cutting; determinative mineralogy and lithology; "thesis."

Professor Eustis died January 11, 1885. He was then "Pro- "fessor of Engineering, and Dean of the Scientific Faculty." He had served as Professor thirty-six years, and as Dean* twenty-three years. In announcing his death, President Eliot wrote: "Professor Eustis' gifts as a teacher were great; and "he has left behind among his pupils a keen sense of obligation "for the intellectual benefits they received from him. He had "an extraordinary power of clear, concise, logical statement, a "quick appreciation of a pupil's difficulties, and a steady pur- "pose to be thorough himself, and to make his pupils thorough. "Though reserved by nature, to his pupils he was always "accessible, frank, and cordial. He is entitled to be remem- "bered as one of the founders of the Scientific School; for, as "first Professor of Engineering, he planned, and for thirty- "five years directed, the whole course of study in that important "department of the School."

This period, from 1880–1887, was a very critical one, both for the Scientific School, and for the work in Engineering, at Harvard. In President Eliot's report for 1880–1881 he had stated: "The graduates in engineering have of late been few "in numbers, but they have been thoroughly taught, and have "promptly found appropriate employment." In his report for

* Eben Norton Horsford was Dean of the Scientific Faculty 1861–1862. There appears to have been no Dean of the Scientific School prior to 1861. The School was "under the superintendence" of its Faculty.

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1881–82 Dean Eustis had written; "Undergraduates of the "college are now allowed to elect, either in course, or as extras, "or by special petition, all the courses of the engineering "department of the Scientific School, and all these courses have "been attended by undergraduates of the college during the past "year."

These statements reveal important changes in the relations of the Scientific School to the College — changes which had been made possible by the growth of the elective system in the College. The election of courses in the Scientific School by College men, as President Eliot affirmed, "greatly increased the "amount and improved the quality of the scientific work in the "University"; but the authorities of the Scientific School, in 1884, held that the possibility of entering the College and electing Engineering Courses, was responsible for reducing the number of students in the School.

Winfield Scott Chaplin was appointed Professor of Engineering June 8, 1885; and was made Dean of the Faculty of the Lawrence Scientific School, November 30, 1885. Professor Chaplin, like his predecessor, was a graduate of the U. S. Military Academy at West Point. He had served two years in the Army; had practiced engineering; and had had a varied experience as Professor at Bates College, Maine; as President of the Military Academy of Japan; and as Professor at Union College, N. Y.

In Dean Chaplin's first report he points out that all the Engineering courses, with one exception, could be counted for the degree of A. B. — that, indeed, there was in the School "but one course which a student of the College may not elect "and receive credit for." He notes that this "completes a pro- "cess which has been going on for many years, by which the "College has gradually adopted as its own all the instruction "given in the Scientific School." He raises the question whether the Scientific School "ought to be continued as a "separate organization."

President Eliot seems to have been inclined to answer negatively the question thus raised by Dean Chaplin. In his report

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for 1885–86 President Eliot says: "The Lawrence Scientific "School has seen most of its functions assumed by the College ".... Even in the department of engineering, all the "necessary elementary instruction in modern languages, chemis- "try, physics, and geology, and all the preliminary mathematical "instruction, are given in and by the College; so that the best "way to get the degree of Civil Engineer is to take, first, the "degree of A.B.; and then spend one or more years as a graduate "student upon technical engineering studies."

President Eliot further suggested that the Lawrence Scientific School as a separate organization be discontinued; that the College Faculty should recommend candidates for the degree of S. B.; and that the "Academic Council should recommend "candidates for the graduate degree of Civil Engineer, the "underlying degree being either A. B. or S. B.": and he proposed that the name "Lawrence" should be given to the building then occupied by the School, as well as to certain professorships in engineering, etc.

These proposals received serious consideration. The alarming decrease in the number of students forced action. In the year 1885–86, twenty-two students were registered; and in 1886–87 only fourteen, in the whole School. A reunion of graduates of the School was held in November, 1886, in connection with the celebration of the two hundred and fiftieth anniversary of the founding of Harvard College. Among the plans discussed were these: (1) To unite the College and the School; (2) To use the funds of the School for special and higher instruction in the subjects named by the founders; and (3) To concentrate the work of the School on engineering.

In support of the third plan Dean Chaplin urged that its adoption would permit the retention of the name of the School; and that then the "one department which has not, since the "early days of the School, received any assistance, would thereby "be strengthened, and put more nearly on an equality with other "departments." Neither plan was wholly adopted.

In his report for 1887–88, Dean Chaplin notes that plans for uniting the College and School had failed; and that it "now

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"appears probable that the separate existence of the School will "be continued indefinitely." He then points out that the problem had become how "to arrange in the best way the "several four-year programmes which lead to the degree of "Bachelor of Science."

President Eliot states in his report for 1887–88; "The "strongest argument in favor of maintaining, for the present, "the separate organization of the Scientific School is, that the "School prepares young men for certain professions, ... and "that the 'group,' or prescribed; combination, system of studies "which obtains in the School, is better adapted for this specific "purpose than the open elective system which prevails in the "College."

The courses of study composing these programmes, or groups of studies, were in the main prescribed; and were chosen mostly from the courses of instruction offered by Harvard College. As compared with the elective work in Harvard College, the work in the Scientific School was prescribed by programmes, or groups of courses. The student might choose his programme — either of engineering, chemistry, geology, biology, etc. — but, this being chosen, the courses of study in it were, for the most part, prescribed. Election of studies by groups, had been the policy of the School for years; and, being reaffirmed in 1887, it has since been sustained and enlarged by increasing the number of programmes, and by such modifications of them as experience has dictated and means have permitted.

Early in the year 1885–86 a committee had revised the several four-year programmes* of study in the Scientific School, "mainly in the direction of greater freedom of election within "the prescribed schedules." The courses of the engineering programme were in some cases expanded, and in others re-arranged; a few courses were shifted to different years; and electives were introduced into the first, third, and fourth years. In the third year, the course in German gave place to a new course in "Hydraulic, water-supply, and sanitary engineering."

*Professor Chaplin appears to have introduced the word "Programme" to refer to the four-year curriculum, or schedule, of studies.

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In the fourth year the work in applied mechanics and designing was much increased. The elective courses had to be chosen from a variety of courses in chemistry, physics, natural history, philosophy, history, political economy, English, French and German.

The revised programme of Civil and Topographical Engineering adopted in 1885–86 was as follows: —

"*First Year* — Analytical geometry; mechanical drawing; "descriptive geometry, and perspective; surveying, plotting, "and topographical drawing; elementary German or French; "one course elective.

"*Second Year* — Practical applications of plane and spherical "trigonometry to surveying, astronomy, and navigation; dif- "ferential and integral calculus; applications of descriptive "geometry; levelling and topographical drawing; and advanced "German.

"*Third Year* — Graphical statics; building materials, and "their application to structures; elements of mechanics; "hydraulics, water-supply, and sanitary engineering; advanced "French; one course elective.

"*Fourth Year* — Applied mechanics and constructive engi- "neering; designing; discussion of existing structures, and "working out of projects preparation of thesis; one course "elective."

This programme stood without essential modification during Professor Chaplin's connection with the School, until 1891.

In 1888–89, a new four-year programme in Electrical Engineering was instituted. The courses included were as follows:

"*First Year* — Chemistry; analytic geometry; elementary "mechanics; mechanical drawing; descriptive geometry, tint- "ing, isometric drawing, shades, shadows, and perspective; "French, or German; shopwork.

"*Second Year* — Electrostatics, electrokinematics, and parts "of electromagnetism; electrodynamics, magnetism and electro- "magnetism; differential and integral calculus; the elements "of mechanics; English.

"*Third Year* — Thermodynamics and the kinetic theory of "gases; heat engines and dynamos; telephone and tele- "graphic apparatus; advanced differential and integral cal- "culus; dynamos and accumulators; shopwork; English.

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"*Fourth Year* — Trigonometric series and spherical har-
"monics; mathematical theory of electrostatics and electro-
"kinematics; mathematical theory of electrodynamics and elec-
"tromagnetism; thesis."

Students who completed this programme satisfactorily received the degree of "Bachelor of Science in Electrical Engineering."

In Dec., 1890, mathematical courses especially designed for engineering students, were organized by Dean Chaplin. These courses were given as alternatives with the College courses until 1892–93, when they replaced the College mathematical courses in all the programmes of the Scientific School. They were given from the beginning by James Lee Love.

In 1891, Comfort Avery Adams, a graduate of the Rose Polytechnic Institute, Cleveland, Ohio, was appointed Instructor in Electrical Engineering. The work on dynamos, in the third year, was at this time considerably enlarged; and a new course in "industrial applications of electricity" was added.

In 1891 Dean Chaplin had the pleasure of announcing a gift of $10,000 from Mrs. Benjamin Rotch for a new laboratory; and in 1892 the Rotch Electrical Laboratory was ready for use in all the laboratory work in electrical engineering.

The elementary workshop instruction has been given since 1893 in the shops of the Manual Training School, founded in the city of Cambridge by Frederick H. Rindge. The instructors of the Lawrence Scientific School still use the shops of the Rindge School for the shopwork courses. These are now given wholly in the summer.

Professor Chaplin resigned in 1891 to accept the chancellorship of Washington University, St. Louis, Mo. His immediate successor was William Hubert Burr, a graduate of the Rensselaer Polytechnic Institute of Troy, N. Y. Mr. Burr had been Professor there from 1876 to 1884, and was a prominent consulting engineer in New York at the time of his appointment. Professor Burr remained at Harvard one year, 1892–93. He resigned to accept a professorship in Columbia University, New York City. Professor Burr modified the engineering programme very slightly. He changed the third year course in

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"graphical statics, mechanics of construction, and strength of materials" to "rational mechanics, graphical statics, and resistance of materials"; and changed two of the fourth-year courses in "applied mechanics," and in "designing engineering structures" to the following: "general theory of machines, water and wind wheels and steam engines," and "bridges, structures, and foundations." Otherwise, Professor Burr made no changes in the programme, except the substitution of the mathematical courses given especially for engineering students in place of the College courses in mathematics formerly required.

Before considering the remarkable, recent growth of the Scientific School, and the equally noteworthy expansion of the instruction in engineering, which have taken place during recent years, it is worth while to note other important details in the history of the School and of engineering.

From 1849 to 1885, with the exception of the two years 1862 to 1864, the engineering instruction was directed and, in the main, was given by Professor Eustis. After one or two years of experimenting, he adopted a body of instruction which seems to have undergone very little change, either in matter or method, until 1871. Beginning his work, in 1849, in the old Zoological Hall, he moved in 1853 into rooms on the first floor of Lawrence Hall. In 1864 he was assigned additional rooms on this floor; and in 1871 he was transferred to the second and third floors of Lawrence Hall where his quarters were much enlarged. In 1871 an attempt was made, as explained already, to extend the work in engineering; which, previously, and then, and until 1888, meant Civil and Topographical Engineering only. Not much in the way of growth appears to have been accomplished by the changes made in 1871. The additional Professor chosen then remained only one year, and his place was not afterwards filled.

The largest number of students registered in the Scientific School between 1847 and 1885 was seventy-nine, for one year, in 1865–66. The average attendance during this period was about forty-three; the smallest number being sixteen, in 1879–

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80; if we omit the opening years 1847–48 and 1848–49 before the engineering courses were begun, when five and twelve, respectively, were registered. In the first four years, 1847 to 1851, the number of students increased to sixty-nine, followed by a decrease, in 1852, to forty-eight. Then the numbers fluctuated, reaching sixty-nine again in 1858, followed by a decline to fifty-six in 1862. In 1863 the number rose to seventy-six, and in 1865 to seventy-nine. This number was not exceeded until 1890. From 1866 on there was a gradual falling off, with a slight rally in 1872 and 1873; then a slow descent to sixteen students in 1879. In 1880 the number ran up to thirty-seven; but the decline was renewed at once, and only fourteen were registered in 1886–87. This was the smallest number of students in the School since 1848–49. But the ascent began again in 1887; since which time the number has gone steadily up until the number registered during the current year, 1901–02, has exceeded five hundred and fifty.

The number of students registered in engineering has always shown about the same fluctuations as the attendance on the School as a whole. Beginning with eighteen in 1849, the attendance rose to thirty-two in 1851; then dropped to thirteen in 1853. Between 1854 and 1861 the numbers were fairly steady, averaging about twenty-seven. In 1863 there was a falling off to twenty, followed by a rally to forty-one in 1865 when the largest number registered. The attendance then declined to nineteen in 1869; rose again to twenty-three in 1872; fell to four in 1880; rose to eight in 1884; fell again, reaching the smallest number ever registered, viz. one, in 1885. In 1886 there were two; in 1887, four; in 1888, two; in 1889, fifteen; in 1890, twelve; in 1891, thirty-one; and since 1891 the numbers have steadily increased, as will be noted later.

The foregoing summaries do not include, at any time, College students, candidates for A. B., who elected courses in the Scientific School.

There is only one technical school of advanced grade in this country older than the Lawrence Scientific School. This is the Rensselaer Polytechnic institute, at Troy, N. Y. During the

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years following 1847, several technical schools of high grade were established, and grew prosperously. It is therefore difficult to understand why the Lawrence Scientific School remained forty years in a languishing condition. It has been affirmed by Dean Shaler that the public entertained a well grounded fear that, in the older institutions of higher education, the "traditions of the academic boards and of the students whom they "controlled, were in a distinct way opposed to the objects of the "science schools; and there was much reason to question the "expediency of joining the new foundation to the old." The Lawrence Scientific School doubtless suffered for many years its share of this disadvantage, which no longer exists so far as Harvard is concerned. Whatever explanation is offered, one thing seems undeniable, viz., the Lawrence Scientific School has been the open door through which a very large body of modern, and indispensable, instruction has entered Harvard University.

One of the first aims in establishing the School was to offer instruction to graduates; and it seems not incorrect to say that the experiments made in the Scientific School furnished largely the basis for the development of graduate instruction, and of the Graduate School, at Harvard University. Through the Scientific School came, in part, the instruction and research in astronomy for which the prescribed College course was not adapted. In the Scientific School, Benjamin Peirce found his opportunity to offer advanced mathematical instruction unmatched in this country. Here, Asa Gray found a place for botany and botanical research; and Jeffries Wyman, for anatomy. Here, Professor Horsford brought in and developed laboratory instruction in chemistry; and here, Josiah P. Cooke projected the experimental study of mineralogy.

It was in the Lawrence Scientific School that Louis Agassiz received his appointment and did his work. Our debt to him has been well described by President Eliot: — "All education "in the United States and all American science are under the "deepest obligations to Louis Agassiz. He introduced here in "1847 the laboratory method of teaching science.... When "he was appointed Professor there was no laboratory for

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"students, use in the entire University, excepting the dissecting "room for human anatomy in the Medical School..... The "numerous well appointed laboratories of to-day — not only in "Harvard University, but in all institutions of higher learning "and even in well equipped secondary schools — bear witness "to the importance of this reform in which Agassiz was a "pioneer..... He set a high standard of endowment and "equipment, and thereby raised the standard for all other "departments.... he aroused new intellectual interests all "over the country, raised the popular conception of the man of "science, introduced on a great scale improved methods of "teaching the sciences dear to him, and gave a new meaning to "the word teacher."

The collections which Agassiz first placed in the second story of Zoological Hall in 1849 grew so rapidly that in 1853 he crowded Professor Eustis out of the building: and out of these collections has grown Harvard's great Museum of Comparative Zoology, which Agassiz founded in 1859. This Museum has cost, for building, collections and library, more than one million one hundred thousand dollars; and it possesses an invested endowment of over six hundred thousand dollars.

Another successful venture is the Summer School; which annually enables hundreds of teachers, men and women, during six weeks of the long vacation to utilize some of the great resources of the University, gaining help and inspiration for their work in the secondary schools. The Summer School, instituted and fostered by members of the Faculty of the Scientific School, is no small part of the service which the Scientific School has rendered.

The Scientific School has been, from its foundation, an educational laboratory — an institution in which the University makes many of its educational experiments. It must be acknowledged that a satisfactory number of them have succeeded.

The School remains true to its experimental function. Within the last few years the School has furnished, for a second time, a home at Harvard for the study of mining; it has provided adequate instruction in architecture and in landscape archi-

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tecture; and it has recently, for the first time at Harvard University, recognized botony, zoology, shopwork, drawing, civil government and economics, as high school studies worthy to be offered by candidates for admission to a course of higher education; and it has, in addition, and at last, provided opportunity for the proper development of instruction in engineering.

The tide turned in 1887. The status of the School was then fixed on wise foundations. Its position before had always been uncertain. So much of its work had been absorbed by the College that there remained a strong doubt whether the whole School had not best be absorbed. When the College had taken over everything but engineering, and when engineering seemed so weak, it was questioned whether this also had not better be turned over to the technical schools outside of the venerable College precincts, and the School ended. Fortunately, the School survived; for it was worthy.

The changes since 1887 have been many, and in the direction of a rapid upward growth. Some of these changes have already been noted. Space will permit mention of only a few others. In 1890 the "Faculty of the Scientific School" was merged with the "Faculty of Harvard College." Thereafter, the combined "Faculty of Arts and Sciences" had immediate charge of Harvard College, of the Lawrence Scientific School, and of the newly created Graduate School. Professor Chaplin had been Dean of the old Scientific Faculty. He became Dean of the Scientific School under the Faculty of Arts and Sciences. When he resigned in 1891 President Eliot wrote, in his annual report for 1890–91: "There are several causes of the revival "of the Scientific School. The first was the energy and good "judgment of the Dean; the second, the more complete union "of the Scientific School with the College; the third, the "establishment of closer connections between the school and the "public high schools."

In the fall of 1891, Professor Nathaniel Southgate Shaler was appointed Dean of the Lawrence Scientific School in succession, to Professor Chaplin.

In March, 1896, the Corporation combined in one account the

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receipts and expenditures of Harvard College, of the Lawrence Scientific School, and of the Graduate School — the three departments of the University under the Faculty of Arts and Sciences. And in May, 1897, the Corporation ordered that rooms in College buildings be assigned "to persons intending to "enter the Lawrence Scientific School on the same terms and in "the same way as to those intending to enter Harvard College." Thus was taken the last step necessary to fix the University status of a student in the Lawrence Scientific School precisely with that of a student in Harvard College.

For many years, one source of criticism of the Lawrence Scientific School lay in the fact that its requirements for admission were less in amount than those of Harvard College. This was, unquestionably, a serious hindrance to a proper appreciation of the work of the School. The Administrative Board of the School faced this problem in 1896; and, after long consideration, including a conference with an assembly of about sixty Masters of the leading New England preparatory schools, a scheme of gradually increasing the total number of studies demanded for admission, was adopted by the Faculty of Arts and Sciences, on the recommendation of the Administrative Board. The first increase was made in the fall of 1899, having been announced first in the University catalogue for 1897–98. The plan contemplated such an increase as would, in 1903, bring the entrance requirements for the Scientific School to equality with those for the College.

It should be said that the Scientific School uses precisely the same examinations as Harvard College. In all respects, the examinations are identical, and are administered by the same officers. Any subject that can be used for admission to Harvard College can be offered, and counted, by a candidate for the Scientific School. Moreover, ten subjects (botany, zoology, wood-working, blacksmithing, chipping etc., machine-tool work, freehand drawing, projections, civil government and economics) are accepted for admission to the Scientific School, but not for the College as previously noted herein.

In 1896–97, a plan of taking the degree of S. B., in addition

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to A. B. was announced. College students are allowed to register in the Lawrence Scientific School after their third year, or after the satisfactory completion of fourteen courses counting toward the degree of A. B. The degree of A. B. is conferred as soon as the student has completed the required number of courses for it; and, later, the degree of S. B. is conferred when the student has fulfilled the requirements for the latter degree. By a suitable choice of studies during the first three years, students are enabled, by this plan, to win both degrees in five, or six, years. In some exceptional cases both degrees have been earned in four years. President Eliot says: "This, "indeed, is undoubtedly the most profitable way for the indi- "vidual of obtaining the degree of Bachelor of Science; for it "puts the degree of A. B. under the degree of S. B. and so "makes the S. B. represent five, or even six, years of elaborate "training."

In 1893 a very great expansion of the instruction in engineering was begun. During the term of Professor Chaplin, 1885–91, some enlargement was made, mainly in the way of enriching the contents and of improving the methods in courses previously given. Professor Burr, 1892–93, added courses in mathematics and in electrical engineering, and modified in some degree the courses left by Professor Chaplin. No considerable increase of instruction was brought about by either of these men. Professor Chaplin, as Dean of the School in a very critical period, was occupied largely in reorganizing the School to save it from complete wreck. In this he succeeded; and when he left, although the increase had begun, there were not students enough present, nor resources in hand or in prospect, sufficient to justify the increase in expenditure involved in adding new courses. Professor Burr was here too short a time to do more than transmit to his successor the hopeful conditions left by Professor Chaplin.

Ira Nelson Hollis was appointed professor of engineering, May 8, 1893. Professor Hollis graduated from the U. S. Naval Academy as a cadet engineer in 1878, and served in various positions connected with the engineering branch of the

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Navy for the succeeding fifteen years. For three years in the early '80s he was detailed to give instruction in engineering at Union College, Schenectady, N. Y. When he resigned from the Navy in 1893 he was on duty in the Bureau of steam engineering as an assistant to the Engineer-in-chief.

Under Professor Hollis' direction plans were made at once for enlargement: in teaching force, in courses of instruction, and in equipment. In 1893, William Vaughan Moses was appointed Instructor in Drawing and Machine Design, and Daniel Lawrence Turner, Instructor in Surveying and Railroad Engineering. A new four-year programme in Mechanical Engineering was organized and instruction was begun in it in the fall of 1893. Workshop courses were instituted at the Rindge School. In 1894 the number of courses offered was more than doubled; and Rogers Building (the old College Gymnasium) was remodeled and fitted for drawing rooms and engineering laboratories; Lionel Simeon Marks was appointed Instructor in Mechanical Engineering; and Lewis Jerome Johnson, Instructor in Civil Engineering. In 1895 Walter Safford Burke was appointed Instructor in Mechanical Engineering; and the field work in surveying was given for the first time in the summer, on the island of Martha's Vineyard. About this time the equipment of the Rotch Electrical Laboratory overflowed the building erected in 1891–92, and all the available space in the basement of Lawrence Hall was filled. In 1896 Lewis Jerome Johnson was promoted to an Assistant Professorship of Civil Engineering; and Comfort Avery Adams, to an Assistant Professorship of Electrical Engineering. In 1899 Walter Safford Burke was promoted to an Assistant Professorship of Mechanical Engineering; Frank Lowell Kennedy was appointed Instructor in Mechanical Drawing; and Stephen Edgar Whiting, Instructor in Electrical Engineering. In 1900 Lionel Simeon Marks was promoted to an Assistant Professorship of Mechanical Engineering; and in 1901 James Lee Love, to an Assistant Professorship of Mathematics.

In 1892–93 the Department of Engineering claimed one professor and five instructors; in 1901–02 it has one professor,

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five assistant professors, thirteen instructors, and five assistants. In 1892–93 it gave instruction in twelve and one half courses (seven full courses and eleven half courses); in 1901–02 in twenty-eight and one half courses (fourteen full courses and twenty-nine half courses). In 1892–93 there were seventy-one* Scientific students registered in engineering; in 1901–02 there are one hundred and eighty-seven.* In 1892–93 there were two hundred and eighty five † enrollments in the equivalents of full courses in engineering; in 1900–01 there were one thousand two hundred and fifty two. ‡

In 1900 the Department of Engineering revised the three programmes of courses, making the work of the first three years practically the same for all engineering students; the purpose being to devote these years to the general studies that underlie all sound engineering practice, postponing until the fourth year specialization in Civil, Mechanical, or Electrical Engineering. This gives the student a broader training, and makes unnecessary a too early choice of his career.

The courses included in the four programmes in 1901–02 are as follows: —

"*First Year* (in all programmes) — Advanced algebra; "trigonometry; mechanical drawing; descriptive inorganic "chemistry; rhetoric and English composition; experimental "physics; German or French.

"*Second Year* (in all programmes) — Calculus; descriptive "geometry; mechanism; elementary statics; resistance of ma- "terials; steam machinery (introductory course); advanced "experimental physics, *or* general descriptive physics; English "composition.

"*Third Year* (in all programmes) — Applied mechanics; "hydraulics; engineering laboratory; thermodynamics; metal- "lurgy; generation and utilization of electrical energy; machine "design."

*This does not include students registered in other programmes, nor College students, who took engineering courses.

† Two hundred and six enrollments by Scientific Students and seventy-nine by College Students.

‡ One thousand and fifteen enrollments by Scientific Students and two hundred and thirty seven by College students.

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Students choosing civil engineering are *required* (and all others are *recommended*) to take the summer courses in plane, geodetic, and railroad surveying before the beginning of the fourth year. Students choosing mechanical or electrical engineering are *required* (civil engineers are *recommended*) to take the summer courses in shopwork before the beginning of the fourth year.

"*Fourth Year* (in civil engineering) — Common roads; "advanced resistance of materials; water supply and sanitary "engineering; canals; rivers and irrigation; bridges and build- "ings; elementary geology (field and laboratory); contracts "and specifications; engineering conference.

"*Fourth Year* (in mechanical engineering) — Advanced "resistance of materials; advanced engineering laboratory; "machine design; efficiency of heat engines; heating and "ventilation; contracts and specifications; engineering Con- "ference.

"*Fourth Year* (in electrical engineering) — Advanced "resistance of materials; direct current dynamo-electric "machinery; alternating currents and alternating current "machinery; dynamo design; electrical engineering labora- "tory; electrostatics; electrokinematics and parts of electro- "magnetism; electrodynamics, magnetism, and electromagna- "tism; contracts and specifications; engineering conference."

In the early spring of 1901 the Scientific School acquired, through the generosity of friends of the engineering department, a large tract of land on the southeastern shore of Squam lake in New Hampshire; where a commodious camp has been built for the use of the courses in surveying. Here the classes went for the first time in the summer of 1901. The combination of lake, and plain, and mountain, to be found at the Harvard Engineering Camp, makes the place extremely well adapted to its purposes.

In the fall of 1901 Pierce Hall began to be used by the engineering department. This great building was erected with a part of the munificent, unrestricted, bequest of Henry Lillie Pierce. It provides lecture rooms, store rooms, rooms for the engineering library, and ample laboratories for the work of the engineering department. A large amount of new equipment has been placed in it, in addition to what had been collected in

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the Rogers building and in Lawrence Hall. A description of this building will be found in another part of this number of the Journal. It will be sufficient therefore to say that now, at last, after fifty-three years, the Department of Engineering at Harvard University is provided with a home befitting the magnitude and dignity of its work. This home owes its origin to the great development of engineering instruction at Harvard University, guided by the wise prevision and prudent administration of Professor Hollis.

The Department of Engineering during many years attracted few students, and possessed scanty equipment; but it may fairly claim to be judged during those years by the distinguished careers of many of the men who were trained by it. Of the results of the work of recent years it is yet too early to speak. That the department is now in full tide of successful growth, we have abundant cause to be thankful. That much has been done is plain; that much remains to be done, in providing both instruction and equipment, none know better than those in charge.

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PIERCE HALL.

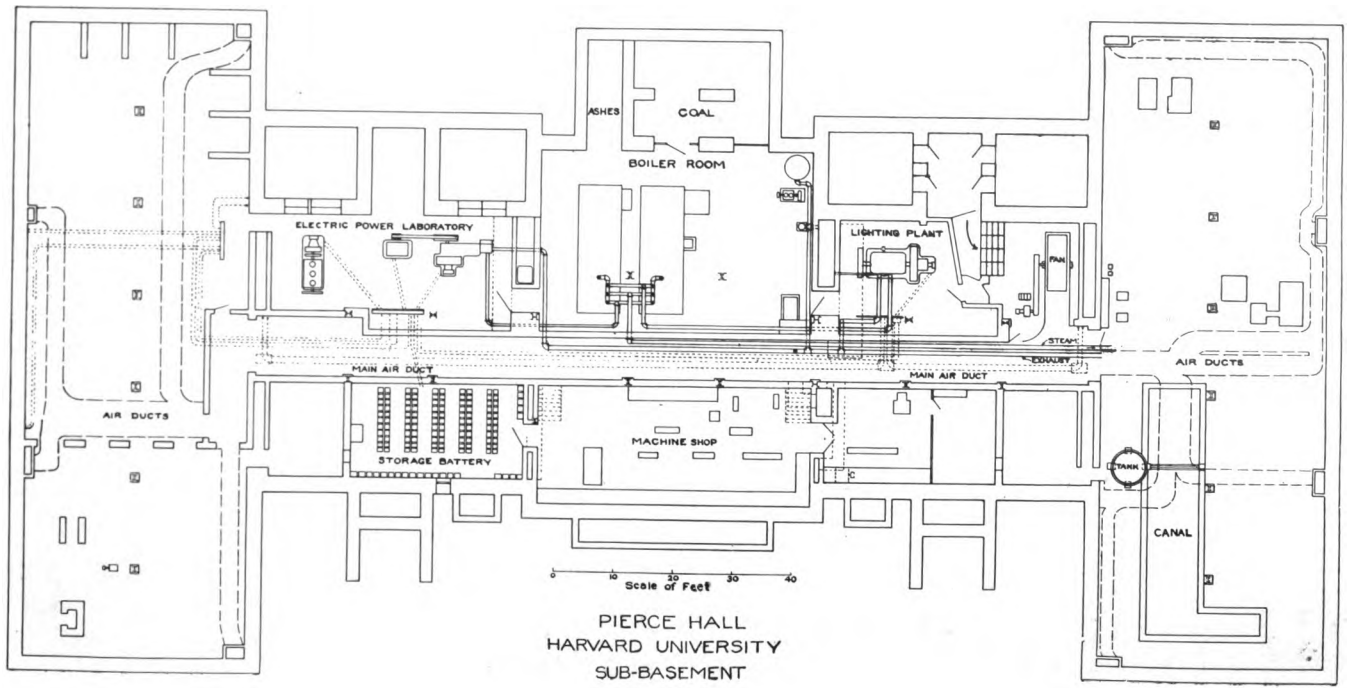
IRA NELSON HOLLIS.

Professor of Engineering.

THE new building now occupied by engineering at Harvard is the successor of two small buildings. When the department was first established, and for thirty years after, no special quarters were necessary, as the several subjects were taught by means of lectures and recitations. Surveying was given in the grounds of the University and in the neighboring fields, where practical exercises were possible; and the drawing connected with descriptive geometry and topography required only well-lighted rooms. The whole conception of engineering was limited to what is now known as civil engineering, in its narrowest sense. Laboratories were not equipped, as the school began before the modern development of technical training had been thought of.

In 1893, with the complete making over of the department into a division containing civil, mechanical, and electrical engineering as sub-divisions, new quarters became imperative. A small extension had already been added to Lawrence Hall for a workshop and electrical laboratory. There some practical work in electricity was done in 1892; and although the rooms did not suffice for the increasing number of students in the Scientific School, they were made to serve. Later, additional rooms were fitted up in the basement of the Lawrence building, and in them were placed the measuring instruments, the storage batteries, the photometers, and some high tension motors and generators. An old octagonal building formerly used as a gymnasium was converted into a laboratory for mechanical and civil engineering during the summer of 1894. The interior of the shell was torn out and two floors were put in, thus giving the building three floors. The top floor was used as a draughting room.

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PIERCE HALL
HARVARD UNIVERSITY
SUB-BASEMENT

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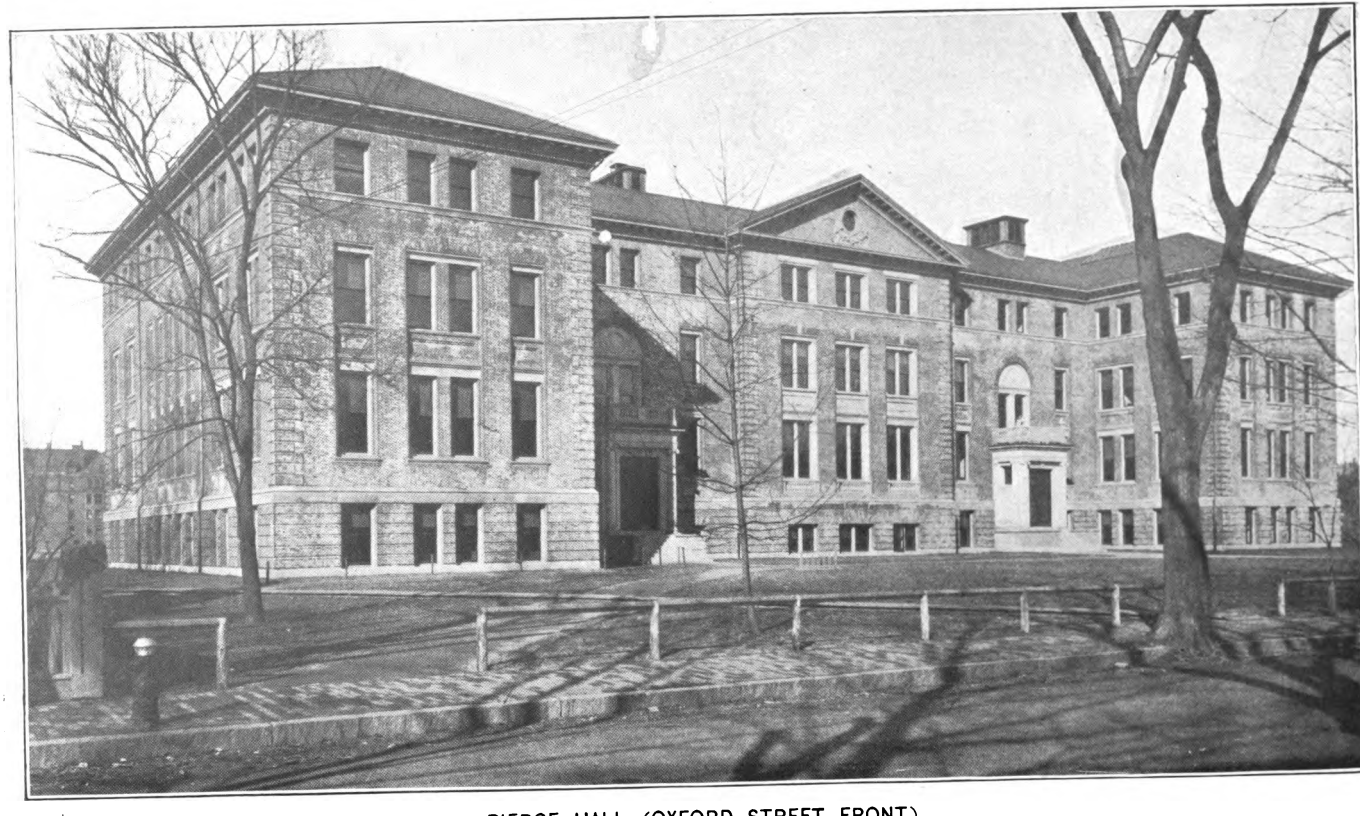
The middle floor was made into offices, a lecture room, and a draughting room, and the lower floor was a laboratory. In the last named, the machines usually found in laboratories were placed. There were testing machines for metals and building materials, steam engines for running small tests, pumps and tanks for experimenting with water, air and oil.

When it became evident in 1899 that the rooms available for engineering were overcrowded, the Corporation of Harvard College appropriated one hundred and seventy-five thousand dollars for a new building, to be used principally by the engineering courses. It was to be called Pierce Hall, after Henry L. Pierce, from whose great bequest the money was taken. During the preparation of plans and specifications, a sudden rise in the cost of materials brought the bids for construction far above the estimate, and a delay followed, to await settled prices. But in the early summer of 1900 a satisfactory bid was obtained, fully thirty thousand dollars above the original appropriation. In May, ground was broken, and the building was completed in time for use during the college year, 1901-1902. The classes were moved in between the middle and end of October, and the year has been spent in transferring and arranging machinery. The equipment will, however, not be complete for several years, as it is not to be purchased at once, the policy of the department being to provide machinery as it can be used profitably by the students.

The building is of brick, with limestone trimmings. The inside is not plastered, but is finished in brick, with oil paints in all rooms where machinery is used, and cold water paints in the lecture rooms, draughting rooms, and offices. The primary idea has been to construct a useful building with no unnecessary finish on the inside. It is intended to house the departments of civil, mechanical, and electrical engineering, all of which are classified under one division. The mathematics for the Scientific School are under the charge of this division, and therefore receive quarters in Pierce Hall. There are accommodations for other departments in case it is found necessary to use the rooms for other lectures than those in engineering.

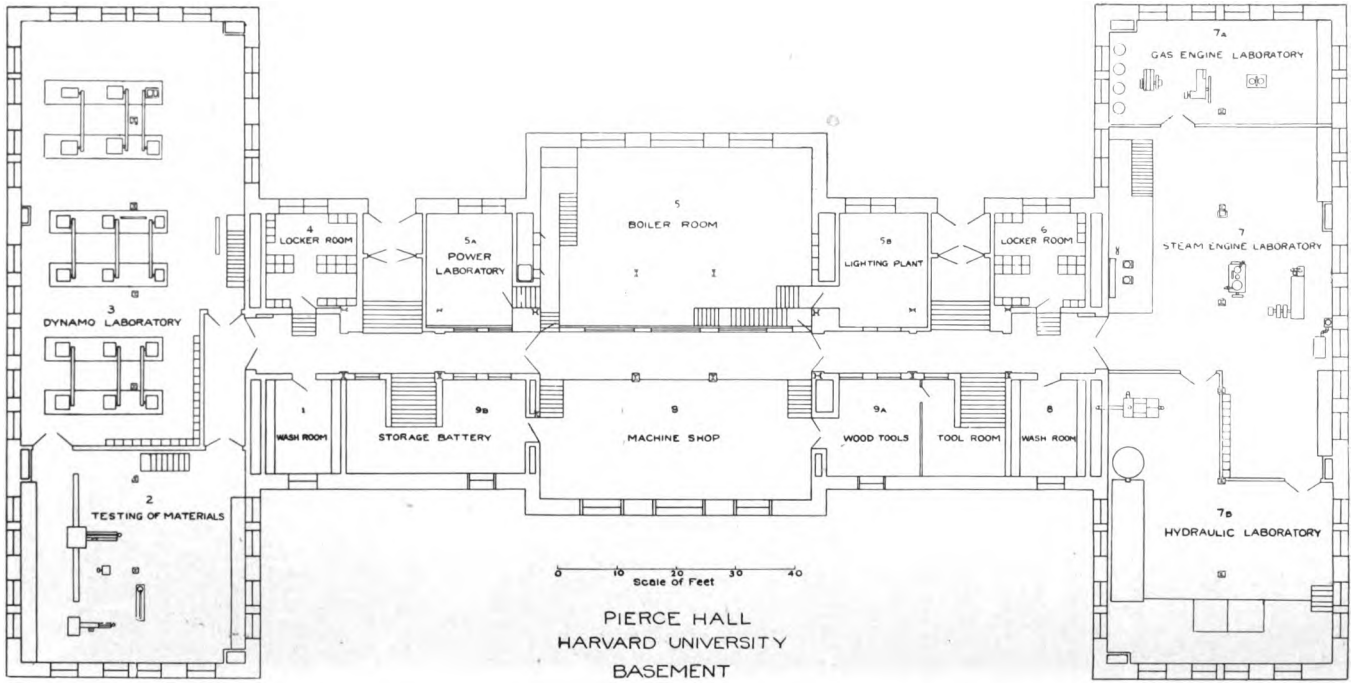
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PIERCE HALL (OXFORD STREET FRONT).

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PIERCE HALL
HARVARD UNIVERSITY
BASEMENT

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The plan of the building, of which drawings are published in this issue, is intended to give a maximum amount of light and air to every room. There are two large wings and a central structure, connected by stair halls containing lecture rooms, small draughting rooms, and offices. The wings measure 113 x 42 feet; the central part, 50 x 64 feet; and the stair halls 46 x 49 feet. The outside dimensions are thus 232 x 113 feet, and the ground covered is 17,200 square feet, exclusive of the outside areas and the coal holes. There are four floors, a basement, and an attic; and the floor surfaces available for all purposes, including storage, are as follows:

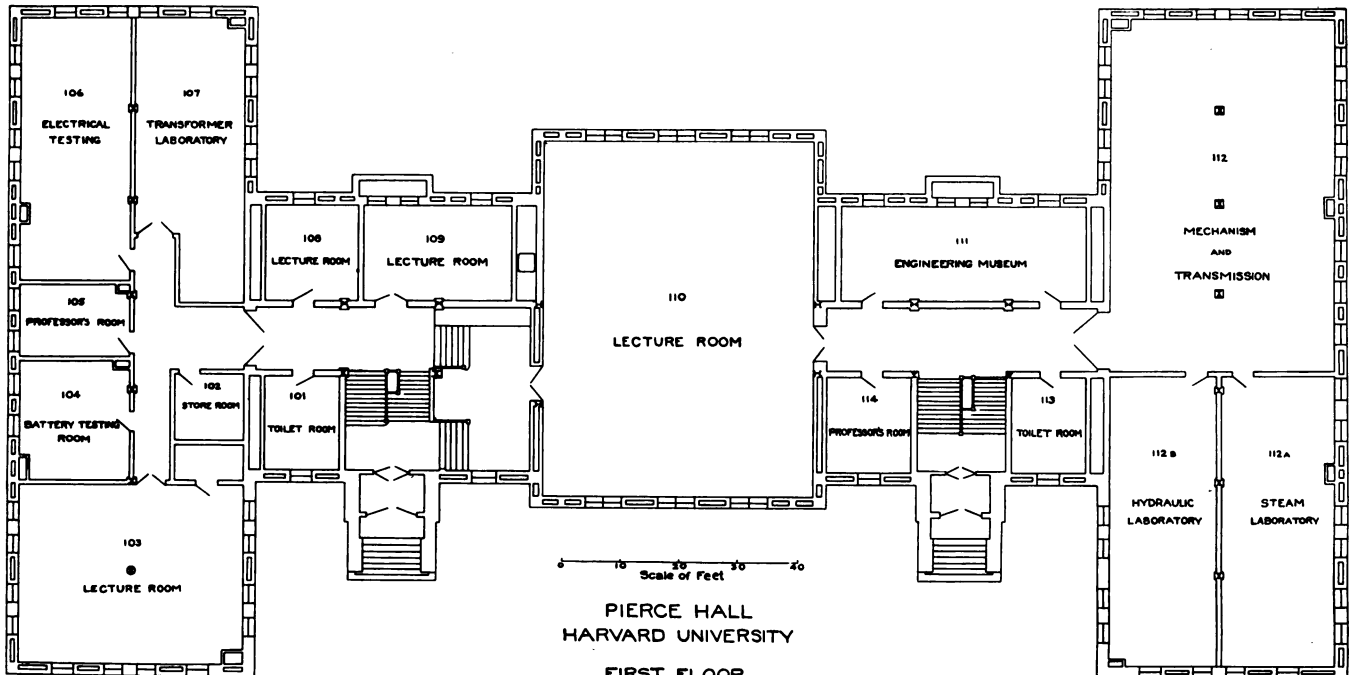
Lecture rooms,	11,495 square feet
Laboratories,	20,640 " "
Draughting rooms,	11,938 " "
Professors' rooms,	1,906 " "
Library,	1,351 " "
Boiler and engine rooms,	4,446 " "
Store rooms and basement,	11,420 " "
Total floor space,	63,196 square feet.

This floor space is exclusive of halls, stairs, entries, washrooms, and air ducts.

The draughting rooms are located on the top floor, the two larger rooms being used mainly for the first year elementary drawing, and the second year instruction in descriptive geometry and graphical statics. The advance work in designing is placed in three smaller rooms, where blue-prints and books of reference can be kept. The drawing tables for elementary instruction are made specially for the room. Each is fitted with drawers for twelve students, and four can work at each one simultaneously. The room holds comfortably one hundred and eight men. Individual desks or tables are provided in the other draughting courses.

The central structure contains four recitation rooms on the top floor, for sections in mathematics and other subjects where the number of students in a section is limited to thirty. On the

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PIERCE HALL
HARVARD UNIVERSITY

FIRST FLOOR

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second floor, in the center, is a lecture room for one hundred and twenty students, and a library in which can be placed six or seven thousand volumes. The library contains now about five thousand volumes. The room is divided into three parts; one for periodicals, the second for bound volumes of periodicals and for text books, and the third for office and administrative details. On the lower floor is a lecture room for three hundred students. There are eight other lecture rooms in the stair halls and wings, three of them capable of holding one hundred students, and the others from twenty to thirty-five.

The laboratories are mainly confined to the two wings. The south wing contains the machinery and apparatus for electrical engineering, and for testing materials of construction. The north wing contains all the other machines for research and experimental work. Several small rooms are provided for special work by the instructors and advance students. Some idea of the proposed uses of the rooms may be gathered from the following statement. The accompanying drawings will indicate the location of each room in the building.

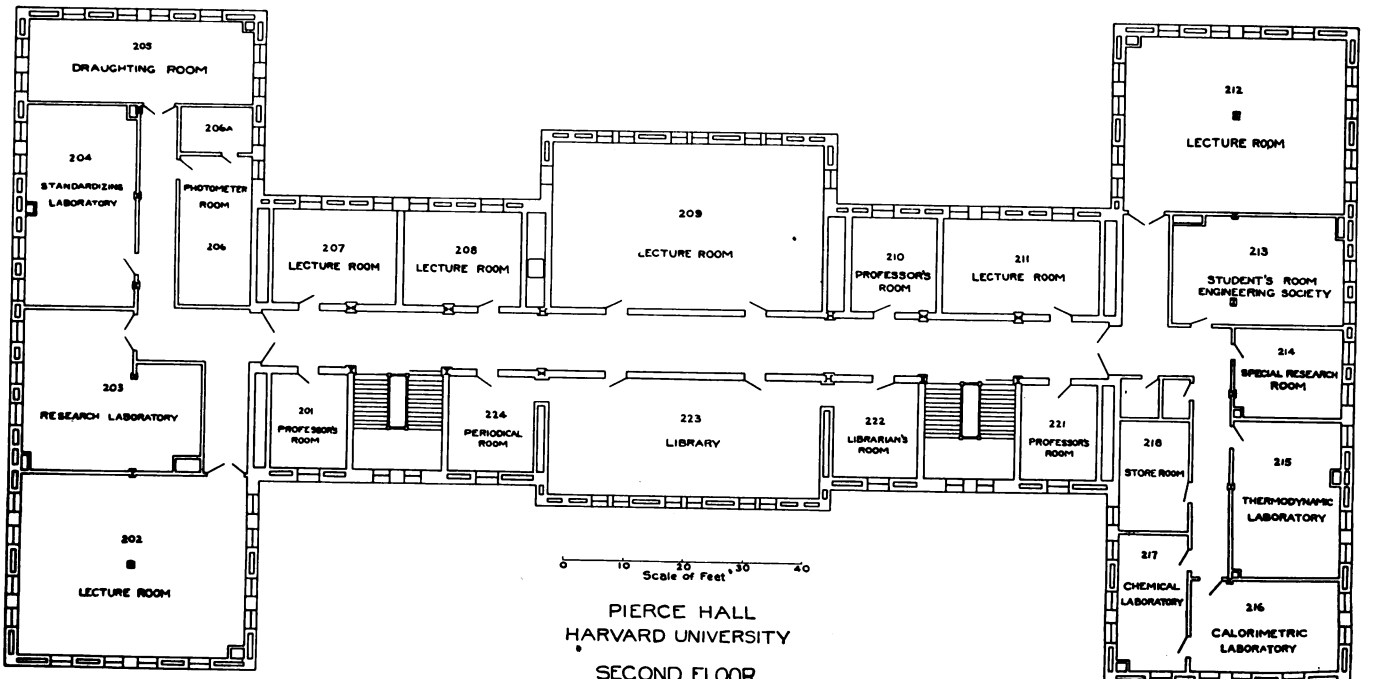
North Wing—

Room 7a: Laboratory for gas engines, oil engines, hot air engines, and refrigerator machinery.

Room 7: Laboratory for investigations of steam engines, condensers, pumps, air compressors, and in general of machines used in power stations.

Room 7b: Laboratory for hydraulics. This room is fitted with a large vertical tank for water pressure up to 150 pounds per square inch and the necessary tanks and apparatus for experiments with nozzles, orifices, weirs, and turbines. The water is supplied from a cistern by a Blake pump delivering either into the vertical tank or into a large tank near the roof. The latter is for the purpose of maintaining a constant head of about 60 feet. Its horizontal section will be 560 square feet, and the water level will be maintained by means of a float or an overflow. The water is intended to pass into the vertical tank or directly into some smaller tanks for weir measurement. From the vertical tank it may be discharged into a large cast iron

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PIERCE HALL
HARVARD UNIVERSITY
SECOND FLOOR

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tank 21 feet long by 6 feet wide by 4 feet deep. Passing over a weir from this into a channel, the water may be allowed to flow into either of two weighing tanks, each capable of holding about 700 gallons. A cistern or canal underneath serves as a supply for the pumps and as a reservoir for receiving the discharge from the tanks.

Room 112: Laboratory for general problems in applied mechanics, such as the efficiency of belts, ropes, chains, and gears; the frictional resistance of surfaces; the investigation of governors, blowers, and transmission dynamometers.

Room 112a: Laboratory for calibrating and investigating steam gauges, indicators, calorimeters, and other instruments used in engine and boiler tests.

Room 112b: Laboratory for small hydraulic experiments.

Room 214: Laboratory for special research of instructors or advanced students.

Room 215: Laboratory for thermodynamic problems, heat conduction and radiation.

Room 216: Laboratory for the heat values of fuels; solid, liquid, and gaseous, and for the heat tests of lubricants and other materials.

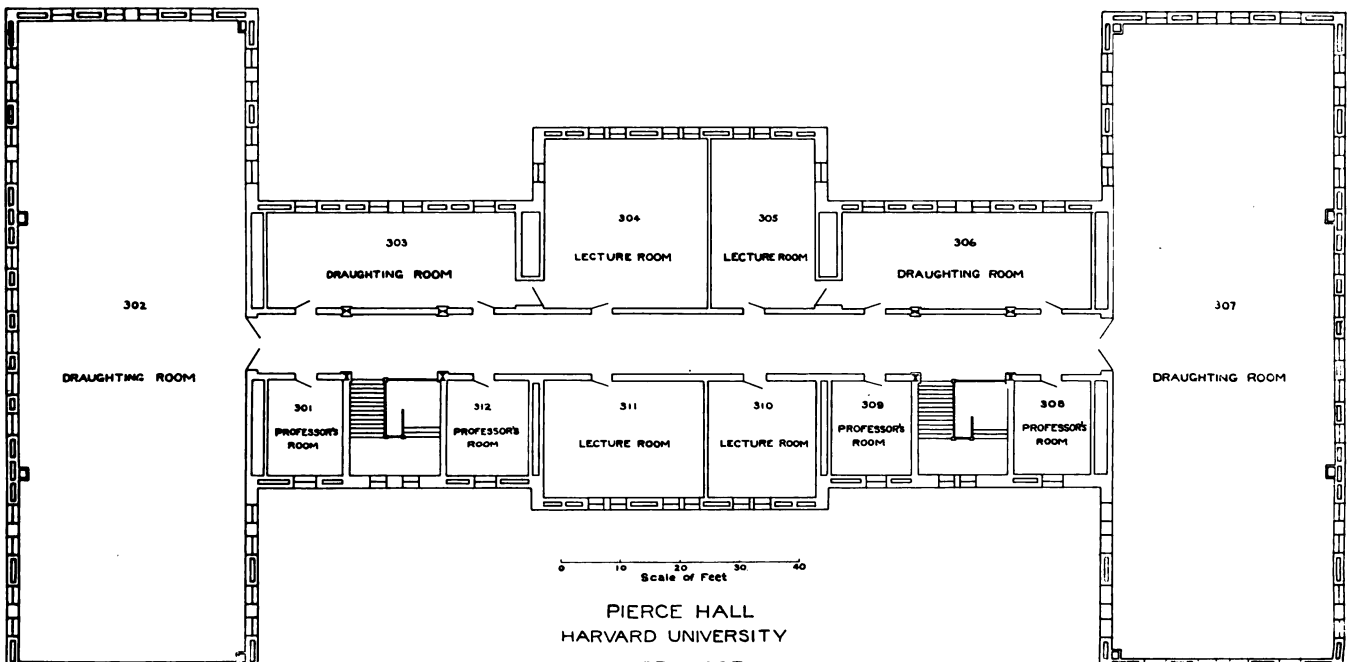
Room 217: Laboratory for the chemical analysis of gases, coals, and lubricants.

South Wing —

Room 2: Laboratory for building materials. There are several testing machines, the largest capable of a tension or compression test of 200,000 pounds. The cement testing is temporarily located in this room.

Room 3: Dynamo laboratory. The larger part of the testing of dynamos and motors is carried on in this room. The machines are arranged in pairs on heavy benches, each pair consisting of a dynamo and a motor connected by a belt. All shafting is thus avoided, and the arrangement is very flexible, as means are provided for the easy shifting of the machines. Extra heavy foundations are laid across one end and a part of one side of the room, for the support of large machines. The equipment, at present, consists of about twenty-five machines, including

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HARVARD UNIVERSITY
THIRD FLOOR

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generators and motors for direct and alternating currents averaging about 6 K. W. capacity, two modern railway motors, one 50 H. P. variable speed motor for testing large machines, and a 10 K. W. rotary converter.

Room 102: Apparatus store room.

Room 104: At present used mostly for the testing of batteries. The equipment is a considerable variety of primary and secondary cells with accessories, — the beginning of an electrochemical laboratory.

Room 106: Elementary electrical testing, including some light dynamo and motor work. The apparatus is mostly of a simple character; resistances, bridges, galvanometers, electromagnets, etc., with one small pair of dynamos.

Room 107: Transformer laboratory, for transformer testing of all kinds. The equipment is a variety of transformers, including several special experimental transformers and one of 20 K. W., 40,000 volts, for insulation testing; also instruments, rheostats, etc.

Room 203: Research room. Special apparatus will be set up here from time to time as required.

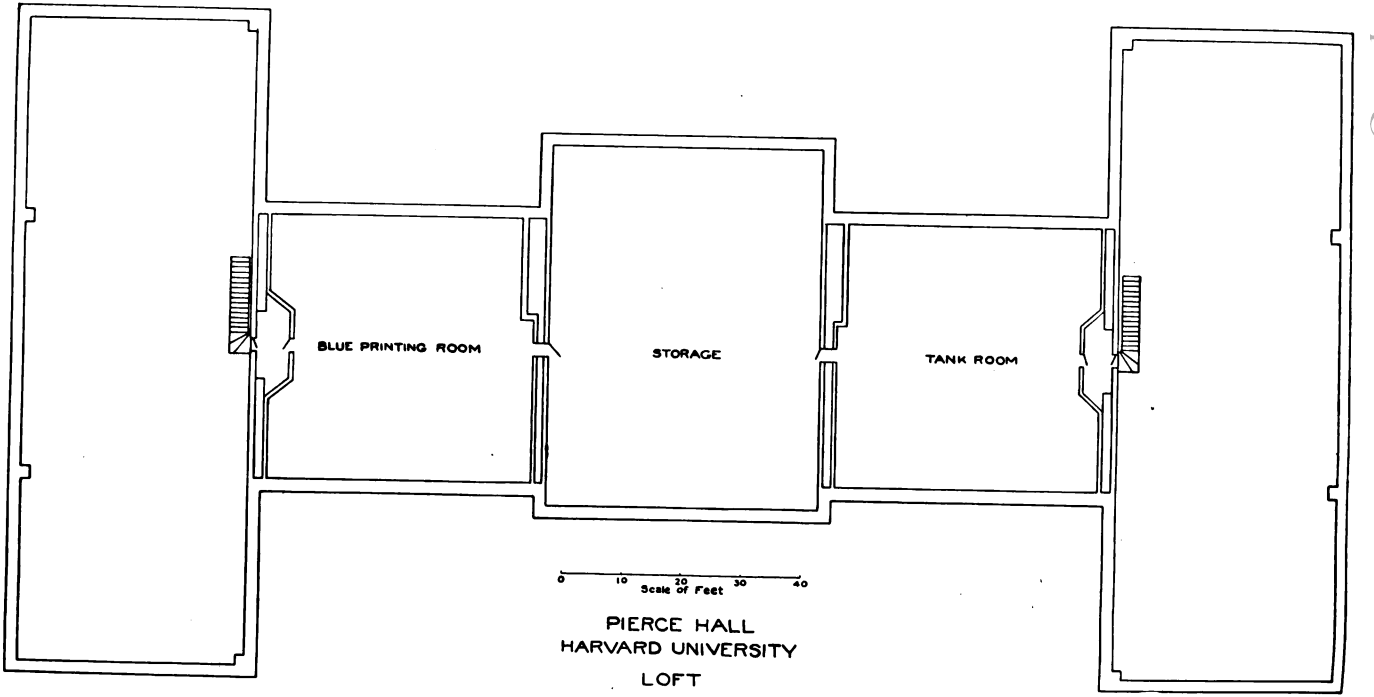
Room 204: Standardizing laboratory, for the calibration of instruments. The apparatus consists of a motor-generator set for supplying large currents at low voltage, a pair of Weston laboratory standards with shunts and multipliers, a potentiometer, a Kelvin balance, and electrostatic voltmeters.

Room 205: Electrical engineering design room. Used by Senior electrical engineers for dynamo design, for working up the results of tests, and for general conference. The equipment consists of drawings and parts of machines, illustrating their construction.

Room 206a: Arc lamp room for the inspection and testing of arc lamps. The room is fitted with about fifteen arc lamps of various types.

Room 206: Photometer room for the photometry of arc and incandescent lamps. The room is equipped with a 5-meter Reichsanstalt photometer complete with accessories, a portable photometer, and an illuminometer.

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Central Structure —

The boiler room is fitted with pumps and apparatus for steam tests and other investigations. There are two Babcock-Wilcox boilers of 125 commercial horse power each, designed for 225 pounds pressure. One of them is fitted with a superheater. The valve connections are arranged so that steam can be supplied from either boiler directly to the lighting engine, the high tension power engine, or to the steam laboratory. The heating system will be explained later.

The work-shop is intended mainly for making new apparatus, and for repairs, but it is also used for experimental investigation on cutting tools and on the power to drive machine tools. On one side of it is a tool and store room, and on the other a battery room where there are storage batteries capable of supplying light to all parts of the building likely to be used during the evening. There will be 140–200 ampere hour chloride accumulators.

The power laboratory, located opposite to the storage batteries, contains a gasoline engine of 34 H. P. direct connected to a Crocker-Wheeler generator, for charging the batteries and for lighting the building during the warm months. In the same room with this engine is a compound steam engine for supplying a 500 volt current to the electrical laboratory. It is direct connected to a 50 K. W. 500 volt Westinghouse generator, and it is also belted to a 50 K. W. General Electric compensated, revolving-field alternator, arranged for single-phase, quarter-phase, three-phase, or six-phase, and for various voltages. The latter machine is intended for experimental work in the electrical laboratories.

The building is lighted by a 100 K. W. 120 volt Westinghouse generator. The current from this machine is also used for power purposes. So far as possible shafting is not used in the building, all power being developed from the current by means of separate small motors placed in the various rooms.

The heating system is both direct and indirect, and is by hot water, with a circulation forced by a small centrifugal pump placed in the boiler room. The exhaust steam is passed through

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a large hot water heater, so that comparatively little supply is needed from the boilers when the engines are running. A small, secondary, high-pressure heater is provided as a make-up for very cold weather and to serve in emergencies. Each room has a radiator sufficient to maintain only a very moderate degree of heat, but air is discharge into the rooms at a temperature of about 70°. It is supplied by a Sturtevant blower in the basement, driven by a Westinghouse motor of 20 H. P. The air passes through three large cast iron stacks, where it may be heated to any desired temperature. From the fan it passes through a long air duct, which extends from one end of the building to the other, and branch ducts pass out and up through the different walls of the building. The general idea of the system is well shown in the sub-basement plan.

At present the equipment of the building is intended to meet all the requirements of a modern school, and other machinery will be added as seems necessary in the future. Room has been provided for the ordinary developments of ten or fifteen years.

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INSTRUCTION IN ENGINEERING AT HARVARD UNIVERSITY.

LEWIS JEROME JOHNSON, A. B. '87; C. E. '88.

Assistant Professor of Civil Engineering.

Fifteen years ago civil engineering was the only branch of engineering taught at Harvard. Professor Chaplin had then recently been called to Cambridge and had found Harvard activity in engineering at the lowest ebb which it had reached since Abbott Lawrence's far-sighted gift in 1847.

Under Professor Chaplin's régime the renaissance of Harvard engineering began at once, and at the time of his call to the chancellorship of Washington University in 1891, the new order of things was established. Prior to his time, instruction had been almost wholly text-book work, with some practice in the draughting-room and field. Laboratories there were none. Early in the new administration, a couple of testing-machines — one for general work with metals and timber, the other for cement — found their way into a small and well-nigh forgotten room in the basement of Lawrence Hall. About the same time a wing was added to Lawrence Hall which was rapidly fitted up as a laboratory to meet the needs of the newly established work in electrical engineering. Soon after Professor Hollis's appointment, in 1893, a course in mechanical engineering was started, the equipment for testing materials was much extended, hydraulic apparatus was procured and the Old Gymnasium had to be pressed into service to house the increased plant. The Old Gymnasium had long been abandoned to the storage of ladders, lumber, and other resources of the college carpenter, but the oft-displayed genius of Harvard University for remodeling old buildings was able to make even this neglected building blossom out again into active service as a fairly serviceable, if much cramped, engineering laboratory.

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With the development of these laboratory facilities there came, of course, a corresponding increase in laboratory instruction, and with the growth in equipment came a corresponding growth in the number of teachers, and in the number of students in attendance upon their courses, so that to-day engineering has a high place in the instruction given at Cambridge, whether measured by the number of courses offered or by the attendance upon them. Before Professor Hollis's appointment the number of teachers of engineering had never exceeded four, with the head of the department the only one above the rank of instructor. At present the teachers in the division of engineering number 24, including 1 professor, 5 assistant professors, 13 instructors, and 5 assistants. This count does not include several assistants in the summer surveying, not now appointed.

In the conditions now existing at Harvard there is much that is to be found in all the foremost centers of engineering instruction in this country, but there are two features of the situation here which are specially significant and which will consequently be developed to some length in this article.

The first of these features is the close affiliation of the instruction in engineering with that in other arts and sciences. At Harvard, teachers and students of engineering are thoroughly united with the general life of the University. Students in the Lawrence Scientific School, and students in Harvard College who are candidates for degrees in the same year are regarded, as a matter of custom, as members of one and the same undergraduate class. In other words, for purposes of undergraduate social and athletic life, Harvard College and the Lawrence Scientific School are completely amalgamated. Moreover, rights to the dormitories, dining halls, and gymnasium are accorded to all students of Harvard on equal terms, and the college life of an engineering student is identical with that of any other College or Scientific School student.

The teachers of engineering are continually in close touch with teachers of other branches of science, of the languages and of the humanities generally, being members of the same faculty with them and serving with them on its various committees.

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The scheme of organization which brings about this unification is a somewhat peculiar one and, as it is not generally understood by Harvard men, whether in college or out, a somewhat full explanation of it seems worth while.

The branches of Harvard University known as Harvard College, the Lawrence Scientific School, and the Graduate School are and have been since 1890 under the control of one faculty — the Faculty of Arts and Sciences — a faculty co-ordinate with the Faculty of Law, the Faculty of Divinity, and the Faculty of Medicine.

The Faculty of Arts and Sciences and the Faculty of Medicine, each being charged with the administration of more than one body of requirements for degrees, delegate much of the detail work of administration and discipline to sub-committees called officially Administrative Boards. The Faculty of Arts and Sciences has three of these boards, concerned respectively with Harvard College, the Lawrence Scientific School and the Graduate School, and the Medical Faculty has two, identified respectively with the Medical School and the Dental School. The chairman of each of these boards is *ipso facto* the Dean of the branch of the university with which his board deals. Students engaged in satisfying the sets of requirements for the degrees peculiar to these five schools, or, for that matter, to the Law School, Divinity School or Bussey Institution are registered in their respective schools. A student in Harvard University may then be registered in any one of eight different schools, and be under the direction of any one of five different faculties.

A second set of committees of the Faculty of Arts and Sciences, responsible like the Administrative Boards directly to the Faculty, are the fourteen Division Committees, so-called, which are charged with the immediate direction and development of the fourteen divisions of instruction offered by this Faculty. These divisions are:

I. Semitic Languages and History.
II. Ancient Languages.
III. Modern Languages (incl. English).

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IV. History and Political Science.
V. Philosophy (incl. Education).
VI. Fine Arts (incl. Architecture).
VII. Music.
VIII. Mathematics.
IX. Engineering.
X. Physics.
XI. Chemistry.
XII. Biology.
XIII. Geology (incl. Mining and Metallurgy).
XIV. American Archaeology and Ethnology.

The official status of engineering is thus precisely the same as that of any of the other divisions just mentioned. In order to obtain the degree of Bachelor of Science in Engineering or other branches, a student must be registered in the Lawrence Scientific School at least one year, and to obtain the degree of Master of Science in Engineering or other branches he must be registered in the Graduate School at least one year. Since about three quarters of the instruction offered in the Division of Engineering counts for the college degree of A. B., a student of engineering may conveniently be registered in Harvard College, and many are so registered. Some of these are planning to enter the Scientific School after graduation, others are taking such courses as are of special interest without expecting to become practising engineers. The great majority of students of engineering are, however, as a matter of practice, registered in the Lawrence Scientific School following a prescribed course of study leading in four years from the secondary school, to the Bachelor's degree in Civil, Electrical or Mechanical Engineering.

It should be observed that the opportunity for an engineering student to be enrolled in Harvard College for a large part of his course affords a very easy and natural means for those who can afford it to lengthen their period of study by one or more years, according to the extent to which they wish to broaden their education. For such, the first three or four years of their course would naturally be spent as students in Harvard College (where under the elective system they can make their

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course of study as nearly identical with the first three fourths of the prescribed course of the Scientific School as they may wish) and the rest in the Lawrence Scientific School and possibly in the Graduate School. A specific programme which students are encouraged to follow is one which requires five years in the University, at the close of which they will have received the degree of A. B. and finally that of S. B. in one of the three branches of engineering. There are strong grounds for believing that this practice is destined to be adopted to a steadily increasing extent, and that the day is not far off when professional instruction in engineering at Harvard will be given only to those who have obtained the degree of A. B. or its equivalent just as is the case at present at Harvard with professional instruction in the law, medicine and theology. Then those intending to become engineers will shape their college courses with that fact in mind just as those intending to become lawyers, physicians or clergymen do at present, electing freely from the very wide range of studies open to college students such subjects as lend themselves to their particular tastes and plans. Many students of engineering now voluntarily adopt this plan, just as many students of the older professions did before it was required of them for entrance to the professional schools of the University. It seems likely that the total length of residence in the University required for obtaining the professional degree in engineering will remain for the indefinite future materially shorter than is the case with the legal, medical and theological degrees.

A line in President Eliot's latest report in which he says "the policy of the University is to make the degree of A. B. the fundamental primary degree of the University, and to use no other in competition with it" is a clear surface indication of the tendency toward making formal professional instruction in engineering exclusively graduate instruction. As is perhaps plain already, this change bids fair to be brought about at the proper time with almost no shock, and in fact, as has been intimated, it has already come automatically into operation to a considerable extent. There has been operating against the

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PIERCE HALL (FROM HOLMES' FIELD).

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evolution toward the consolidation of the A. B. and S. B. degrees an influence which is steadily disappearing and which will be done away with altogether by the close of this year. That influence is the lower entrance requirements for the Scientific School than for the College. By 1903, this condition will no longer obtain and the boy in the preparatory school with engineering in mind, and confronted by equally difficult courses of preparation, will be more likely than ever to enter Harvard College, with wide elective privileges and encouragement to broaden, rather than the Scientific School with its prescribed course and more difficulties in the way of broadening.

Under the circumstances which have been described, with the students of engineering registered in three different branches of the University, the only adequate means for stating the extent of the interest in engineering at Harvard is to give the total number of enrollments in its courses. This number for 1900–01 was 1252, which places the Division of Engineering third in this respect among the fourteen divisions of the Faculty of Arts and Sciences. The only divisions with larger enrollments are those of Modern Languages, and of History and Political Science, with 3926 (of which slightly over one half are in English) and 3153.5 respectively. The Divisions of Philosophy, Fine Arts and Ancient Languages are the three nearest neighbors on the other side with enrollments of 889.5, 837.5, and 733.5 respectively. In making this count, enrollments in half courses have been given, in all cases, half the weight of those in full courses.

In total number of full courses or equivalents offered, the Division of Engineering ranks fourth with 28.5 such courses, being surpassed in this respect by the Divisions of Modern Languages, History and Political Science, and Ancient Languages with 78, 46, 34 respectively, and closely followed by the Divisions of Geology, Mathematics, and Philosophy, with 25.5, 24.5, 23.5 respectively.

The instruction in engineering which in 1901–02 was given in Lawrence, Massachusetts, Sever Halls, and the Old Gymnasium, is now given under one roof in the new Pierce Hall, so that the

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Division of Engineering is housed in a manner quite analogous to the Divisions of Chemistry and Physics. The instruction in shopwork and surveying is given respectively at the Cambridge Manual Training School and at the Harvard Engineering Camp at Squam Lake, N. H.

The second feature specially alluded to at the outset is the exceptional precaution against premature specialization. This is to be found in the fact that the four-year courses prescribed for the bachelor's degrees in Civil, Electrical and Mechanical Engineering are precisely alike in the work of the college year until the fourth year. In other words, candidates for these degrees have precisely the same work prescribed for them for the first three quarters of their course except the summer work.*

This policy arises from the belief that there can be no sound specialization in any branch of engineering until after a broad and thorough training in the principles underlying all kinds of engineering practice. It is believed that three years is none too much to devote strictly to this kind of study, and that specialization upon a less broad foundation is obtained at too great a sacrifice, and entails a loss in breadth of view extremely difficult to make up afterward. The tendency of modern engineering practice toward specialization is strong enough to make it clear that no fostering of that spirit is specially called for in the schools, but rather that it is the duty of the schools first of all to provide broad training, and not to feel disturbed if they do not find time to drill students in matters of detail in which they cannot fail to become versed in the midst of active life outside the school.

This policy is felt to carry with it important additional advantages in conducing strongly to wisdom in the choice of

*The summer work includes Land Surveying, Railroad Surveying and Geodesy, prescribed for all candidates in Civil Engineering, and Shopwork, prescribed for all candidates in Mechanical and Electrical Engineering. All candidates are advised to take as much of this summer work as they can in addition to what is required of them. To do the whole, portions of two summers would have to be devoted to it, the requirements in surveying and shopwork being each covered in a part of one summer.

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a specialty when the time comes to make such choice, and also in broadening to the utmost the field of usefulness open to the young graduate, and making him feel less obliged to adhere to his school specialty in spite of better and more attractive opportunities unexpectedly appearing, as not infrequently happens, in one of its close kin. Men labelled "mechanical engineers" sometimes do good service as forestry experts, etc., and "electrical engineers" do their *alma mater* credit as strictly structural engineers.

While all these considerations point clearly to the need of broad training in general principles it is recognized, of course, that these principles must be seen and studied in close relations to their applications if they are to be fully grasped, and moreover that a considerable amount of time must be given to the more extended application of some particular sets of these principles, *i. e.*, to specialization. In apportioning the time between the fundamentals and the more extended applications, Harvard has taken the position that *not less* than three years should be devoted in the University to the former, and *not less* than one year to the latter. The former work is to a large extent a matter of then or never, while the year of specialization is more like the first year of professional life, spent in the University under the direction of those whose sole business it is to aid young men in acquiring knowledge, instead of in the employ of those whose business it is to gain as much as possible for themselves by employing them.

Specialization, it is frankly recognized, can only be begun in school; it continues, however, throughout one's professional life. It is recognized also, that only such features of this specialization as can be done *well* in school should there be undertaken, and all that can be done better outside should frankly be left to be done outside. The school should, however, prepare a man to make rapid progress from the foot of the professional ladder where every well informed and right minded graduate will see that he must and should begin.

In closing, it may be said by way of summary, that the policy of Harvard with regard to engineering is to offer every incentive

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to breadth of preparation for the profession, to provide specialized instruction of a carefully selected sort for properly prepared students, and, incidentally, but by no means least, to bestow upon engineers, as upon the members of the older professions, a full and cordial share in her life, her traditions and her ideals.

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THE STEAM LOOP AND HOLLY GRAVITY RETURN SYSTEM.

CHARLES GILBERT WILSON.

(A lecture delivered before the Harvard Engineering Society, December 4, 1901.

The Steam Loop and Holly Gravity Return System is a system designed to return to boilers condensation from steam mains, separators, jackets, coils, heating systems, and similar steam using devices. As it supplies a long-felt want in the commercial and engineering world, it may be well to preface a detailed description by enumerating a few of the causes which have led to its general adoption.

Until recent years, the presence of more or less water in steam, while deplored, did not receive the careful attention that it deserved. Not until numerous accidents directly traceable to water in steam mains and engine cylinders had occurred, was it realized that with the ever increasing size of engine units as much care should be exercised in ealing with the water of condensation and entrainment as with any other important detail of the plant.

For a time, drips were allowed to blow free into the atmosphere, and while this undoubtedly removed the water, the great waste involved by blowing live steam outboard was obvious.

Traps were next and are to this day employed, and while, theoretically discharging nothing but water are easily disarranged. A leaky trap blowing steam is a common sight in a steam plant.

Returning the drips to boilers by means of a receiver pump is a method quite generally in use but it still necessitates the use of traps and brings up some interesting questions of economy.

Sometimes where engines or drips are located at a sufficient height above boilers it is found possible to return condensation by gravity, and thus do away with the necessity of traps.

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In the early '90's there appeared on the market a device called the Steam Loop and Holly Gravity Return System, and while in itself a very simple application of Nature's laws was so unusual and so apparently impossible that it was made the sub ject of much scepticism. This brings us to a detailed description of this device and introduces some interesting points of economy and safety in comparison with the methods of water return previously mentioned.

That so simple an application of Nature's laws as is involved in the Steam Loop and Holly Gravity Return System should not have been turned to useful effect in earlier years, seems strange at first thought; but as one looks deeper into the subject, the reasons become more apparent. While every engineer is familiar with the phenomena on which it depends, it has been interesting to note that even those best informed in practical steam engineering, or theoretical research in thermo-dynamics, seldom understand its action on first acquaintance, though they soon recognize in it a new combination of functions.

Its mission is the simple and useful one of returning water of condensation to steam boilers. Its chief characteristics are: that its action is continuous, rapid, and positive; that it is a closed system operating under widely varying conditions, without valves or adjustments.

The principles upon which its action depends are as follows:—

Difference of pressure may be balanced by a water column. Vapors or liquids tend to flow to the point of lowest pressure. Rate of flow depends upon difference of pressure and mass. Decrease of static pressure in a steam pipe or chamber is proportional to rate of condensation. In a steam current water will be carried or swept along rapidly by friction. It will be evident that the system therefore contains no mysterious factors even though like the steam injector, it has been called a "paradox."

Fig. 1 is a diagram of the apparatus. The steam pipe passes from the boiler to a separator near the engine, which separates the water of condensation and entrainment from the steam.

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The drip from the separator is below the boiler and evidently, were a pipe run from this drip outlet directly to the boiler, we should not expect the water to return of itself. Moreover, the pressure in the boiler is say, 100 lbs., while in the separator it is, due to the decrease in pressure in the steam pipe, only 95 lbs. Thus, the water must not only flow up hill to the boiler, but also must overcome the difference in pressure. The device to return it must perform work and in so doing some heat must be lost. The loop therefore may be considered as a peculiar form of motor.

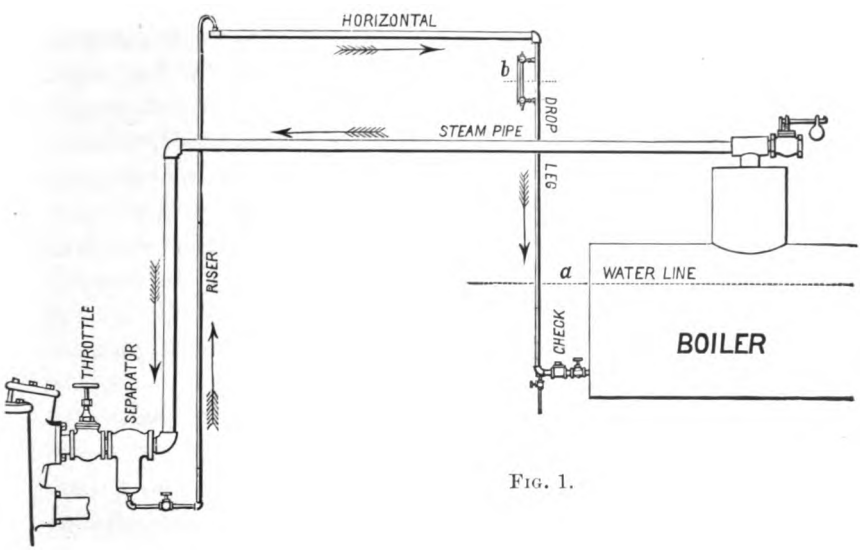


FIG. 1.

We are now prepared to examine the mechanical operation of the system.

Again referring to Fig. 1, showing the system in its simplest form, it will be observed that from the separator drain there leads a pipe called the RISER, which at a suitable height empties into the HORIZONTAL. This leads to the DROP LEG which is connected with the boiler anywhere under the water line. The Riser, Horizontal and Drop Leg form the loop, which is

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simply an open pipe giving free communication between the separator and boiler. For convenience, stop and check valves are inserted, but they take no part in the loop's action.

Suppose steam is passing, the engine running, and the separator collecting water. The pressure of 95 lbs. assumed at the separator extends, with even further reduction, back through the Loop, but in the Drop Leg meets a column of water which has risen from the boiler, where the pressure is 100 lbs. to a height of about 10 feet. This is the Hydro-static head, equivalent to the 5 lbs. difference in pressure. Thus the system is placed in equilibrium.

Now the steam in the Horizontal or upper portion of the System condenses slightly, lowering the pressure to 94 lbs., and the column in the Drop Leg rises two feet to balance it, but meanwhile the Riser contains a column of mixed vapor and water which also tends to raise to fill the Horizontal, as its steam condenses, and being lighter than the solid water of the Drop Leg, it rises much faster. If the contents of the Riser have a specific gravity of only one tenth that of the water in the Drop Leg, the rise will be ten times as rapid, and when the Drop Leg column rises one foot, the Riser column will lift ten feet. By this process the Riser will empty its contents into the Horizontal, whence there is a free run to the Drop Leg, and thence to the boiler. In brief the above may be summed into the statement that a decrease of pressure at the high point of the System produces similar effects on the contents of the Riser and Drop Leg, but in a degree inversely proportional to their density. When the condensation in the horizontal portion is maintained at a constant rate, sufficient to give the necessary difference in pressure, the drop leg column reaches a height corresponding to this constant difference, and rises no further. Thus the System is in full action, and will maintain circulation as long as steam is in use, and the differences of pressure and quantities of water, are within the range for which it is constructed.

No body of water should accumulate in the separator as it is the mission of the system to remove it before it assembles in a liquid mass. It is here that the constant and vigorous action is

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of great utility, enabling the system to act as a preventive of accumulation rather than as a device for removing water after it has accumulated. The separator evidently must be of such a form as to give the sweep towards and through the system better opportunity to pick up the entrained water than is afforded the current sweeping towards the engine, pump, or steam using device. It is interesting to know that experiments on separators as large as 5 x 12′, show that if water be allowed to accumulate to a certain height no further rise will occur, even though much moisture be present in the steam. This proves that the steam sweeping through, carries the water with it, unless that already deposited be drained away. Thus a separator to properly perform its function of drying steam must be empty; while obviously to stop and hold primage its volume must not be impaired by periodic accumulation. Thus, solid water in bulk is to be avoided. Condensation and entrainment should be retained, and returned as spray or films, while primage should be broken up into particles or masses as small as possible, and instantly returned before accumulative effect causes damage. In performing these functions the Steam Loop and Holly Gravity Return System offers a new process in the apparently humble mission it serves.

That separators alone do not generally separate all the mois ture from the steam is quite clearly shown by the fact that a system will sometimes return more water when the throttle is closed and the engine is idle, since the separator must then stop all moisture and the system return it. With the engine running, some moisture will always be carried over. The amount of course depends upon the efficiency of the separator. Experiments on this feature are difficult because of the interference due to the varying amounts of condensation, entrainment and primage on all of which the draft of steam may have more or less effect. It is noticeable, however, that separators of inferior design sometimes give more efficient service when drained by this system, probably owing to the suction maintained at the point of drainage.

Generally speaking, the limits within which the Steam Loop

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and Holly Gravity Return System is applicable are wide, for the principle applies quite as well to great as to small differences of pressure. Similarly an enormous quantity of water may be handled quite as easily as a small amount. The action will continue reliably through long pipes overhead or on the ground. Water may be lifted from levels far below the boilers. The use to which the steam may be applied after the system and separator have dried it of course has no effect upon the system. Wherever steam is so used that it condenses rapidly, as in dryers, steam heating systems, jackets, or steam kettles, this gravity system can be applied to the return of this water of condensation just as from an ordinary separator, and that too, against any difference of pressure.

The above statements illustrate how thoroughly and completely the system can be applied to a wide range of conditions; but when we come down to the practical application, and determine how far it is expedient to apply it, the field contracts somewhat.

To take up the different limiting conditions, and comment upon their degree will show most clearly the practical range through which the system may be made a commercial device.

The application of the system is limited most often by the headroom required for its erection. If the pressure in a separator, dryer, or return from a steam-heating system be ten pounds below the boiler, and a height of about 30′ is necessary to make the return, it is evident that a difference of 50 pounds in pressure would require a height of about 150′. Generally speaking, a line of pipe of that height would not be convenient, inasmuch as it would require some peculiar structure to hold it, although possibly, it might be erected on the side of a smoke stack. In high city buildings where convenient air shafts allow easy support, such an installation might be practicable, but in ordinary manufacturing plants it would seldom be constructed.

While speaking of difference of pressure, attention should be called to the fact that the absolute pressure is of no importance, as the system will work quite as well under low pressure as high. In its construction and operation, we recognize only the difference of pressure. A special case occurs, however, where

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the difference of pressure is very large compared with the lowest pressure in a system. For instance, if a boiler carries 25 pounds of steam and at the end of a series of heating or drying coils the pressure is one pound, then it would be evident that if the condensation in the horizontal or upper portion approximately 100′ high were so performed as to even produce a perfect vacuum, the water column in the drop-leg would stand about 80′ high, but it is doubtful whether the pressure of one pound at the foot of the riser plus 14.7 pounds due to vacuum would be sufficient to force the contents of riser up 100′ into the horizontal or upper portion. If there were a considerable quantity of water to be handled, it would certainly be insufficient, due to the relatively high specific gravity of the riser contents. Such a case, however, is so seldom met with in the practical application of the system, that it scarcely need be considered a limiting condition.

Roughly speaking, differences of ten to fifteen pounds are the largest experienced in good practice, and the system can generally be erected to operate against such differences. Where excessive discrepancies in pressure are observed, it is often desirable to make some changes to diminish differences, for they are usually due to faulty piping. While, therefore, excessive difference of pressure is practically a limiting condition to the use of Steam Loop and Holly Gravity Return System, it is not found to be an annoying interference.

Since the system is placed in equilibrium by the drop-leg column, and this starts from a boiler, no account need be taken of the distance the riser may extend below water level in the boiler; that is, the engine, separator or drying apparatus may be anywhere below with no effect upon the system's action, except the additional work imposed. This would, however, be a limiting condition when the riser column became so long that the pressure at its lower end is insufficient to lift the total weight of mixture to the horizontal or upper portion. For instance, if the system is working under five pounds difference, from 15 to 10 pounds, and if the riser is so charged with water that the specific gravity is 0.1, then if the horizontal further reduces the pressure to 6 pounds, there would be a total forcing pressure up

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the riser of four pounds, which would support a water column 8′ high, or a column one-tenth as heavy 80′ high. The horizontal in this case would stand about 30′ above boiler water; hence, the foot of the riser can extend about 50′ below the boiler. Similar figures for 80 pounds boiler pressure, with 75 pounds at engine and a drop of 10 pounds in the horizontal portion, would allow a riser to run about 150′ below water level.

Evidently the foot of the riser can be elevated to any height but there will be a height depending upon the difference of pressure at which the true functions of the system may seem to become superfluous. Consider the case where the drain is just at a height above boiler water equal to the hydrostatic head due to the difference of pressure, and with no riser in the system, water collecting in a separator to run directly down a pipe, similar to a drop-leg into the boiler. This water must collect in ordinary liquid state and exert gravity pressure before the column can move. The velocity of its exit depends wholly upon the amount that has collected. Should the difference of pressure increase slightly, accumulation would be necessary to cause drainage. This is simply a gravity system. It has no current carrying the water swiftly from the separator and over a hill to a point of safety to the top of a water column on the other side, which may rise and fall from time to time without affecting the flow from the point that is to be drained. A gravity system is a water pipe sufficiently high to overcome the difference of pressure. The Steam Loop and Holly Gravity Return System may be called a gravity system from the boiler to the top of the water column in the drop-leg; but it is essentially a device extending above a balancing column, with such functions as enable it to create a circulation that is not dependent upon gravity or the incoming water of condensation, but wholly upon the flow of steam from a higher to a lower pressure. The device is so arranged that this flow will carry water with it. Therefore, even though the source of condensation is above the boiler, the principle of the system is just as applicable to constantly and positively remove the water as though it were below.

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If the height above the boiler is far in excess of the head due to the maximum difference of pressure, the system may take the form of a straight pipe, the first section of which may be considered a riser, the second a horizontal, and the last or lowest a drop-leg. Such a pipe would be a limiting case, having shape of the system distorted, but its functions retained. The true action occurring in such a pipe has been imperfectly understood. Indeed, it is quite probable that no one considered it deserving of a special consideration until the Steam Loop and Holly Gravity Return System was devised and explained.

It might not be unreasonable to suppose that the application of the Steam Loop and Holly Gravity Return System would be limited by the distance between the separator and the boiler, that its length would introduce complexity or uncertainty of action. Extreme length might impair its action, although even this is questionable, but at the greatest distances thus far met, of 800 to 1000′, no adverse conditions have been encountered. Great distances cause proportional drop of pressure within the loop itself, and require proper allowances to be made in the height of the drop-leg. The temperature of the return on account of the cooling effect of long pipes is also affected, but can be controlled largely by proper covering.

The quantity of water returned depends upon the amount of moisture entrained in the steam, the condensation in the pipe, and the boiler primage. Usually there is no attempt to classify the water appearing in a steam system according to the causes of its existence. Its presence is simply regretted until harm results, and then it may be less considerately mentioned. If water is only to be drained out when it accumulates in considerable volume, it matters little how it is formed, but when we come to handle it systematically, continuously, and with certainty, we must consider the source of the product on which we operate.

Water of entrainment causes steam to be known as wet, and is usually constant in quantity. It may be separated from the steam in several ways, means for this being provided in the various forms of separators, and when so separated, must be led

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away from the main steam current, so continuously, that it cannot again be picked up. Water of condensation is supposed to flow along the bottom, or be swept along the sides of pipes, and is also usually constant in quantity. It requires no true separation, but must be led into a chamber of suitable size in such a manner as to leave readily the column of steam with which it is flowing. As most pipes afford opportunity for water to collect at certain points, and then rush on with the steam, the receiving chamber should have ample capacity. Water of primage is erratic. Its presence is accidental. We cannot estimate its probable quantity or the nature of its passage through the pipe. It may be so received by the pipe as to cause excessive entrainment, as is probably the case when an engine labors, clicks and shows very wet exhaust. It may come over as liquid, and mingling with the water of condensation, cause an engine to slow down, pound and collapse, or spurt streams of liquid water from the exhaust. It may be constant or intermittent, and is always dangerous. It must be led away from the steam current, and received in a chamber whose capacity is considerably larger than that required for water of entrainment or condensation.

A separator must, therefore, provide ample facilities for separating the particles of entrained water from the steam and ample capacity for moderate primage. Extreme primage is, of course, beyond control, and requires cure rather than care. The Steam Loop and Holly Gravity Return System must have a capacity sufficient to discharge continuously the water collected from entrainment and condensation, and a maximum working effort, or a single impulse, equal to taking in one liquid stream the contents of the separator when filled up to a certain limit by sudden primage. If filled beyond this limit we have a flood, whose control is not within the province of the System or any other instrument.

This action while apparently intermittent, is not truly so. It is intermittent with reference to the extra charge of water carried, but the system will simply exert in an emergency its maximum ability, which if constantly required, would not be

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inconsistent with its principle of continuity, although different proportions would then be desirable. Thus, the quantity of water to be handled becomes a limiting condition only when it is so great as to flood completely the system.

To start the Steam Loop and Holly Gravity Return System the air must be removed by blowing out with steam, hence it is proper to inquire whether air would not collect at the high point of the system and gradually reduce the action and make it eventually become air bound. There is certainly sufficient air in steam to produce this action, but in practice it does not. This may be attributed to the high velocity at which the current flows, carrying the air forcibly back to the drop-leg where it enters the water and condensing steam returning to the boilers. To sum up the limitations, we find that the action of the System is practically independent of the distance that the source of supply is above or below boiler, and also independent of the length of return. It is not interrupted by the presence of air, and is capable of handling such quantities of water as usually exist in steam systems. It is practically limited by excessive difference of pressure and by abnormal quantities of water.

A 100 H. P. Engine using 30 lbs. of water per hourly H. P. requires 3000 lbs. per hour. If 10% or 300 lbs. be returned to the boiler per hour, and the difference of pressure between the separator and boiler is 10 lbs., then about 1-275 of 1 H. P. is required to do the work. In the above it will be noted that we have assumed a very large amount of water to be returned, and have assumed a large difference of pressure against which to return it. Consequently the above figures are generous, and it is doubtful whether half this amount of power, or say 1-500 of 1 H. P., is used in the average case. As the Steam Loop and Holly Gravity Return System is required to exert so small a power, it is evident that its efficiency, as measured by our ordinary ideas of economy, might be extremely poor, and yet its efficiency for the purpose for which it is used very high; that is, while its absolute efficiency considered as a pump with which to get water into a boiler might be low, the small amount of energy needed to perform so valuable a service as a continuous return, may make it relatively an article of high efficiency.

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An important factor in its practical efficiency is the improbability of leakage existing, while other methods involve great opportunities in this direction.

There are other interesting developments with relation to efficiency which cannot be stated explicitly because of the large variety of surrounding conditions. They may be indicated as follows: In any system which involves carrying from the boiler steam at a given temperature, and returning a part of the same to the boiler, there must be some loss of heat. The amount will depend on the differences of temperature to which the steam or resulting water is subjected and the time. All systems contemplating the collection of water in volume, handling it through pipes in volume and pumping it back in volume, contemplate or involve the use of apparatus having itself a temperature considerably lower than that of the live steam from the boiler. They also contemplate the moving of a solid body of water which can only be done at a very low rate of speed. Hence any return made on such systems is essentially a wasteful one. The Steam Loop and Holly Gravity Return System makes a return through an apparatus which is small in mass and kept at a comparatively high temperature, while the current through it is extremely rapid, bearing in this respect no relation to any other device. Both the difference of temperature and time are so reduced as to give evidence of its superior efficiency. In fact it may be said that the Steam Loop and Holly Gravity Return System cannot be reasonably compared with any other form of return that has yet been made, as it stands alone in its principle and utility.

This demonstrates clearly the theory, application, economical advantages and limitations of the Steam Loop and Holly Gravity Return System. There remains to be described its variation in form for application to more complex conditions. Where many points requiring drainage are connected to many boilers, some method other than the simple one of radiation at the high point of the system may be advisable. It may be advantageous also to gather all the drips at a common receiving chamber before passing them up through the riser. Such a method is shown in diagram No. 2 where the pipe E takes the drainage

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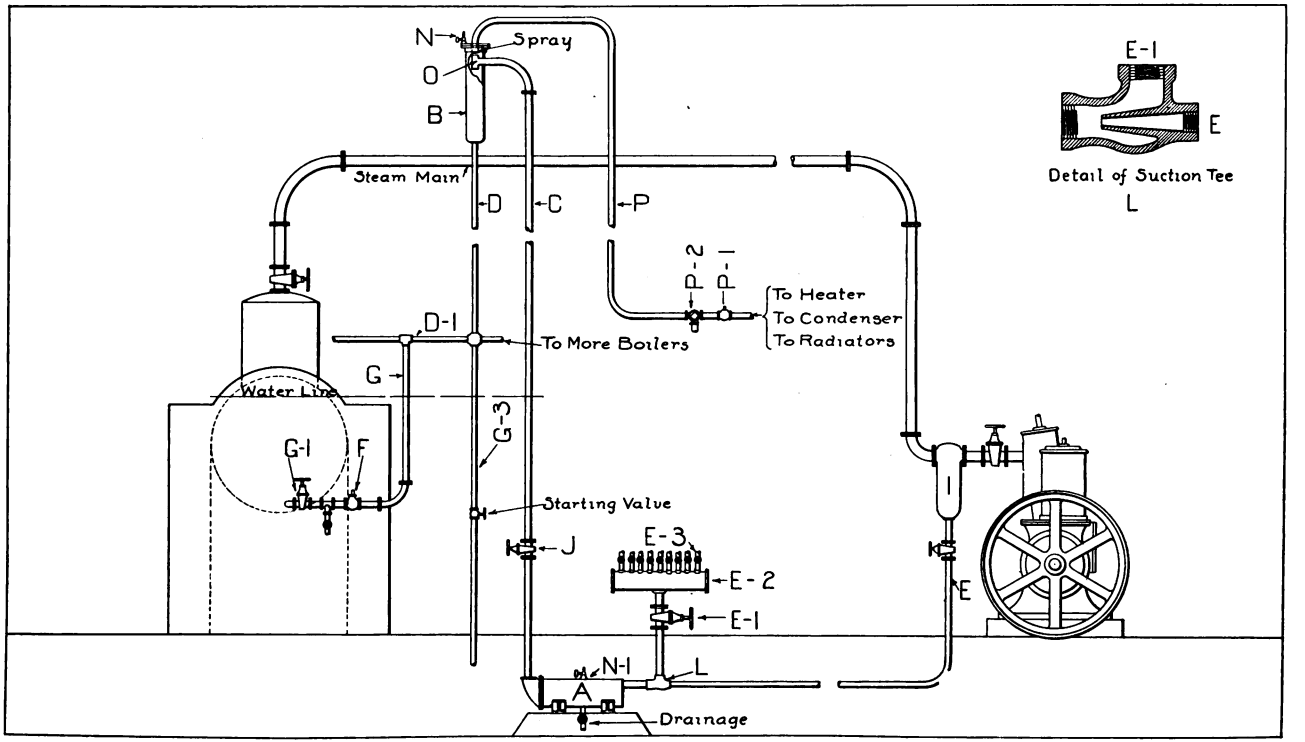


FIG. 2.

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from the separator, steam headers or any suitable place in the live steam pipe, and runs to the Holly Receiver A, connection with which is made through the special suction tee L, shown in detail at the top of the figure. This suction tee is of the McDaniel pattern and is designed on the ejector principle. The velocity of the flow through the small orifice of this tee is sufficient to cause a strong suction on drips returning through the larger orifice which makes more positive and speedy the return of minor and secondary drips. The pipe E maintains nearly the boiler pressure at the receiver A and helps to draw drainage from the header E 2 which receives the drips from all the secondary sources through the pipes E 3. The Holly Receiver A is placed below the lowest point to be drained and serves as a storage for large or unusual quantities of water and enables the riser C to act at a constant rate independent of variable discharges into the receiver should such there be. The condensed water and vapory moisture are carried up through the riser C to the Holly Discharge Chamber B. The purpose of the discharge chamber is to give the water a rapid and easy start down the drop-leg on its way to the boilers. The slightly lower pressure at the discharge chamber necessary to secure the lifting of the mingled steam and water through the riser C instead of by condensation in the horizontal as in Fig. 1 is here produced in either of two ways, first by means of pipe P, and the Holly Reducing Valve P–1 which connects the discharge chamber B with any point where a small quantity of steam can be used economically as in a heater, radiator, or condenser.

Again a three-way cock shown at P–2 can be used in such a way that it will shut out reducing valve P–1 and connect pipe P to the discharge from the feed pump, so that a small spray of water is forced into the discharge chamber. A starting valve for the blowing out of air is shown and also other valves which are used as convenience requires under various conditions but do not affect the principle or operation of the system. The Holly Reducing valve P–1 is an interesting mechanism, capable of adjustment such that the small quantity of steam passing through it issues at practically atmospheric pressure.

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The advantages resulting from the use of the Steam Loop and Holly Gravity Return System may be summed briefly as follows:

1st. Saving the water of condensation, entrainment and primage.

2nd. Saving the heat contained in said water.

3rd. Saving the Steam Systems from water, and thereby reducing liability to accident.

4th. Returning pure water to the boiler.

5th. Preserving uniform temperatures, thus obviating difficulties due to expansion and contraction.

6th. Prevention of direct loss which usually exists from open drains, drips, tanks, etc.

7th. Enabling engines to start promptly.

8th. Maintaining higher pressures at the end of long lines.

9th. Maintaining higher temperatures in jackets, dryers, etc.

10th. Increasing the efficiency when steam is used expansively.

Throughout this article the description has been confined almost wholly to the application of the Steam Loop and Holly Gravity Return System, to the one case where moisture is to be removed before steam passes to an engine or pump. It is thought best to keep this one case clearly in mind, for the Steam Loop and Holly Gravity Return System, thoroughly understood on this basis, may be easily conceived to serve a similar purpose in any other connection.

Where live steam is used for drying purposes the system may be attached directly to the return, thus maintaining a powerful circulation throughout the heating coils, and ridding the system from the condensation which is the natural product of the heating or drying process. In this service however, the System has opened up a new feature, that of drying the steam before it enters such heaters, and it is found to yield beneficial results, by keeping up temperatures and pressures. Similarly steam kettles, steam jackets cylinders, and even steam heating apparatus can be handled with greater ease and efficiency.

The development of the Steam Loop and Holly Gravity

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Return System does not stop with the simple applications here recorded, but has been carried into fields of wider application. Perhaps no device has appeared during late years, in which more thought and careful consideration has been bestowed. Its possibilities have been explored and its limitations studied to such an extent that the limits of this paper will not suffice to enumerate specific features of interest that have not been mentioned.

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EDITORIALS.

The Harvard Engineering Society, with Professor Ira N. Hollis as its first president, was formed in January, 1894. It is to his efforts in a great measure, that the Society owes its existence and present standing. Its object is to promote a general knowledge and discussion of engineering subjects; and to bring its members in contact with engineers in active practice. This is accomplished by obtaining the services of well known engineers to give lectures before the Society at its monthly meetings.

Some of these lectures are well worth preserving; and at its last November meeting, the Society decided to do this by publishing a magazine. At this meeting, an Advisory Board with Prof. Hollis as chairman was chosen to elect editors and supervise the publication of the paper. This board thought it

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advisable to have all branches of Engineering at Harvard represented and accordingly chose the following additional editors: Associate Editors, Stephen Edgar Whiting, instructor in Electrical Engineering and James Ambrose Moyer, instructor in Descriptive Geometry; Assistant Business Manager, Niran Bates Pope, '03; Assistant Editors, Allan Getchell McAvity, '03, Mechanical Engineering Club; Howard Edward Huntington, '04, Civil Engineering Club; Gilbert Simral Meem, Jr., '03, Electrical Engineering Club; Eliot Thwing Putnam, '01, Pen and Brush Club. Besides these lectures, the Advisory Board thought it well to publish articles by professors or instructors, and graduates.

We shall be pleased to receive from graduates, for publication, their addresses, the nature of their present occupation, and any interesting or instructive article.

For the cover design, we are indebted to Mr. Walter Dana Swan of the Pen and Brush Club.

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STORAGE BATTERIES — I.

PHILIP WHITNEY DAVIS, A. B. '93., S. B. '95.

THE storage of energy touches a side of engineering of great importance. Almost every application of power, whether great or small, exemplifies the storage of energy in some form, for convenience, for profit, or as a requisite of successful operation. We see it in the watch-spring, the engine fly-wheel, the tank of a gas plant, the reservoir of a water supply system.

The secondary or storage battery is an electrical reservoir. It does not store electricity quite in the sense that water may be stored in a tank, but converts the electrical energy applied to it into potential chemical energy, which is then available for reconversion into electrical energy at convenience.

The general public, and many engineers even, are scarcely aware of the extent to which the application of storage batteries has been carried in recent years. The idea often prevails that batteries are toys having a scientific interest only, at most fit for practical application in nothing but small work.

Engineers whose practice has brought them in contact with existing battery installations, however, know that the storage battery has attained a development which makes it an important element in modern power station design. The refinements of economy and the necessity for reliability of operation have created a demand which is responsible for this development.

Up to date in the United States alone battery plants aggregating a storage capacity of over 300,000 horse power hours and representing an investment of about eleven million dollars are in daily service in connection with power plants involving the generation and distribution of electrical energy. The vigor of the industry is revealed by the amount of new work under contract for erection, which amounts to nearly a million dollars in value. Some of the existing plants have been six to seven years in service and a few even longer.

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There have been no sudden strokes of genius connected with the success of the modern storage battery. Since the inventions of Planté and others forty years ago, there have been substantially no changes in the basic principle utilized in the finished storage battery. Results have been obtained by slow and painstaking effort directed towards the elimination of operating difficulties and the building up of a knowledge of the requirements of batteries under the different uses to which they can be put in commercial work.

Mechanically speaking a storage battery is a very simple machine. There is little to get out of order or require adjustment. There are no moving parts to need watching or oiling. In fact the battery may be, and often is, locked in a room for hours and still performs its work with entire satisfaction. It consists essentially of two lead plates supporting active materials, a high oxide of lead for the positive and metallic lead in a spongy, finely divided state for the negative. The plates are immersed in dilute sulphuric acid and contained in a glass jar or wooden tank lined with lead.

A battery never gets into trouble suddenly, which constitutes one of its strong points as a reserve. Such of its troubles as are not trivial and easily prevented are usually of a chemical nature or are defects of design, and have come to be thoroughly understood only after much observation and experimental research. It should not be inferred from the foregoing that when the maker has built and installed a good battery free from all possible defects of material or design, there is nothing left for the operator to do. On the contrary the battery must have certain attention at regular intervals and certain rules and regulations must be strictly complied with. Thus it is necessary to read the specific gravity of the acid in two or three cells once or twice in twenty-four hours, and every cell must be inspected once in two weeks. It is also necessary to keep the liquid free from impurities, such as chlorine, nitrogen, arsenic, iron, or in fact any metal other than lead. All these substances and their compounds, even in minute quantities, are detrimental to the life and successful operation of the plates. All impurities known

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to be harmful are rigorously excluded in the processes of manufacture. The water supply which is used to replenish the evaporation taking place from the surface of the liquid in the cells is carefully analyzed. It takes little water to replace the evaporation, but as the impurities do not evaporate, the continual adding of small quantities of impure water would in time introduce sufficient impurities in the cells to do harm. All sorts of seemingly unimportant details such as the effects of temperature and sunlight have been investigated and provided for.

Quite as much care and experience are required in designing and proportioning the plates as in the manufacture of the materials. The shape and details of the plates have been a favorite subject for experiment with inventors and almost every conceivable form and combination of active material and supporting grid has been invented and reinvented, some forms displaying great ingenuity. The chief mechanical difficulty to be overcome is a tendency on the part of the active material to expand and grow unequally in different portions of the plate, subjecting the latter to strains which distort or "buckle" it. The best practice favors the use of a non-active grid made of an alloy of lead with antimony which gives it strength and prevents it from being acted upon while in operation. This grid supports pure lead buttons from which the oxide is formed.

The proportion of active material to supporting grid and in fact the entire mechanical design of the plate is influenced by the class of service for which it is intended. For station work the plates are made very heavy as weight is no object except as influencing cost. The weight efficiency is of course small, being about 550 lbs. per horse power hour at the one hour rate. For vehicle work where lightness is of great importance the design is entirely different and the weight is reduced to 145 lbs. per horse power hour at the one hour rate.

An important step in advance is the building of plates which will furnish high discharge rates of short duration without injury. This feature has a direct bearing on the commercial side, because the higher the rate at which a cell can furnish energy the less is the investment needed to provide for a given

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demand; assuming, of course, that the duration of the demand lies within the time capacity of the cell.

Plates are now made which will stand up under regular discharges four times, and, emergency discharges even eight times, the normal or eight hour rate, formerly regarded as the maximum safe rate. They charge and discharge at these high rates continually in regulating the rapid fluctuations found in railway and elevator work, and also bear the severe strains found in the peak load service of central lighting stations for years without injury. It is worthy of notice that, owing to the very low internal resistance of a cell, there is never any difficulty in actually producing a discharge at a high rate. For example, a railway cell rated at 100 amperes discharge for eight hours might have an internal resistance of about .0003 ohms. It would therefore be capable of supplying on short circuit in the neighborhood of 7000 amperes or 70 times its normal rating. The effective voltage would, of course, be nil and the duration of the discharge extremely short. This cell has a maximum rating of 400 amperes and would not often be worked beyond that point.

The field for storage battery service is naturally very wide, being limited only by that of applied electricity. Cells are now made in standard sizes running from the little telegraph cell weighing complete a couple of pounds up to the big lighting cell weighing over two and one half tons.

The use of the storage battery in large work in connection with electric lighting and railways is the application which appeals most strongly to the general engineer, and it is intended to devote a second article in a subsequent issue to this subject. In the meanwhile the smaller applications are not without interest.

Many thousands of storage cells are now used in place of the old bluestone gravity and other forms of primary cells, for telephone and telegraph, fire alarm and railroad switch service, laboratory work, etc. The ordinary town fire alarm system has 80 gravity cells connected to each circuit, maintaining a steady current flow for six or eight months. These cells cost $56

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when new and the yearly expense for up keep is about $120. Two sets of 30 storage cells (one set being in use while the other is charging) will replace them. The first cost of the latter is $66 and the running expense is $12 a year for depreciation of plates, plus the cost of the current for charging them which does not exceed $20 a year. In addition the floor space occupied by the storage cells is about one fifth that taken up by the gravity cells. The storage cells are also cleaner and more reliable, not being bothered with creeping salts or corroding connections which sometimes result in an open circuit and ring the alarm when not intended.

In modern telephone work where the exchange is operated on the "common battery system" the low internal resistance of the accumulator cell becomes a valuable feature because, as the name of the system implies, the battery is a part of every circuit in use and, were its resistance appreciable, cross talk would result. The energy for the transmission of speech and for the lamp, which lights up and attracts the operator's attention when the subscriber lifts the receiver from the hook, is furnished by a small generator. The effect of the undulating current of the generator would be, however, extremely disagreeable except for the battery which is connected across the mains, thus rendering the supply to the system steady. Standard practice makes use of eleven cells, the size being regulated by that of the exchange but frequently reaching an hour rating of 400 to 800 amperes.

Train lighting employs some fifteen thousand cells. Low voltage lamps are used and the current comes from a dynamo driven from the car axle. Compensation for change of speed is automatic between certain limits and the battery tides over stops and stretches of low speed.

Nothing would be more nearly ideal than electric power for pleasure boats. The machinery is concealed, there is no dust, smell, smoke, noise, or complicated machinery to give trouble. The drawbacks are in the high first cost and in the restricted radius of operation imposed by the need of a charging station. Large boats and yachts usually carry storage batteries for lighting purposes in order to tide over periods when the machinery is not in operation.

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For vehicle work the battery has much the same advantages and disadvantages as for boats. The weight of the battery as compared with other forms of power is of course a disadvantage in a hilly country. The electric vehicle, however, is the only form of automobile which has an absolutely safe source of power. The battery usually has 44 cells because this is the greatest number that can be charged from a 110 volt circuit. Speed control is obtained by forming various series-parallel combinations with the battery in two sections and the motors. Speeds up to 60 miles per hour and distances of 100 miles have been accomplished without recharging. The average vehicle does 50 miles on one charge and is capable of speeds from 15 to 20 miles per hour. The cost of operation varies greatly with circumstances and for certain forms of service it may be less than for horses, especially if the better speed obtained be considered.

Electric freight locomotives operated by batteries are coming into use in factories where the overhead trolley would be in the way. The weight of the battery is an advantage as helping to secure traction. No skill is required by the operator, and the absence of fire risk is a valuable feature. The cost for energy is practically nothing as most factories have their own electric power plants.

Besides the applications just described there are many small uses where from one to half a dozen small cells arranged in portable form in wooden cases answer the requirements. Low voltage lamps, small motors for dental machinery, phonographs, organ bellows, etc., are conveniently operated in this way. The cells may be carried back and forth between the source of supply and the place where they are used. Sometimes where a street supply is not available the energy may be derived from closed circuit primary cells connected up to the storage cells in parallel. The latter accumulate the energy of the former continuously throughout the twenty-four hours and discharge it at high rates in as short a space of time as wanted.

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VOL. 1 JUNE, 1902 NO. 2

ARCHITECTURAL EDUCATION AT HARVARD UNIVERSITY.

HERBERT LANGFORD WARREN.

Professor of Architecture.

THE training of an architect under our modern conditions demands a wider scope than is often realized. An architect who is really to carry forward his art requires to be an artist, a constructor and a scholar; while if he is to succeed in his calling he must also be a good business man. All these capabilities are rarely combined to high degree in any one man, hence the necessity for the development of architectural firms. But architectural education needs to take account of all these sides of this many-sided calling, and no man can rightly regard himself as a well trained architect who has not developed his capacities to some extent in all these directions. Even if he should devote himself to one side only of his profession, whether as principal or assistant, he will need to understand and sympathize thoroughly with all these points of view in order to work to best advantage.

As is stated in our descriptive pamphlet: "architecture is essentially a fine art, the practice of which must be based on a thorough knowledge of construction." The architect must realize that he is dealing with material things subject to physical

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laws which cannot be disregarded with impunity and with which therefore he needs to be familiar. He must also be thoroughly conversant with the practical wants of the people to whom he is to minister, and he must moreover be able to enter into what is best in their ideals and give it artistic expression. These material wants and the practical requirements of construction are the subject matter with which, as an artist, he deals. Indeed the peculiar fascination of architecture lies in the fact that it is at once a fine art of the most exalted and ideal character and is at the same time in touch, as no other fine art is, with the most practical and exacting demands of every-day life. Herein lies its distinctive quality. Its head is in the fine air of the highest regions of the human imagination, but its feet must be planted on the solid rock of obedience to commonplace material wants and immutable physical laws.

As an artist the architect of modern times occupies a peculiarly difficult position. In the elder days of art, in the great periods, architectural style and expression were matters of tradition. On the firm ground of this accumulated but limited experience the architect stood ready for farther advance. He worked grammatically without understanding grammar because the forms were traditional. Accomplishment therefore was a matter of national much more than of individual achievement.

In our day and country we are almost without traditions, and, however much we may deplore the fact, we cannot change our circumstances. We must take our birthright as we find it. Moreover there seems no reasonable probability, that, in any appreciable future, this condition will change. There is only one thing which can be substituted for tradition and prevent our architecture from running, as it so often has, into parrot-like imitation of bygone styles or hopeless and vulgar extravagance, and that is Scholarship.

A scholarly training and a scholarly point of view is the one thing, which — more than all else just now — our architecture needs as a guide and a corrective. If an architect thoroughly understands the history of the forms which he is obliged to take as a starting point, if he knows what constructive conditions,

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what material wants, what ideal conceptions gave rise to them, if he realizes to some extent the conditions of civilization out of which they grew — and at the same time knows and sympathizes with what is best in those of his own day — he will not misuse these forms, he will not combine such as are essentially inharmonious or use for one purpose what was intended and is only truly serviceable for another and totally different one. If besides this an architect thoroughly understands the fundamental principles on which depends the beauty of the fine things of the past, if, from the constant tracing of these laws of design as exemplified in the work of Greece, of the Middle Ages and of the Renaissance in Italy, the observance of these principles has become second nature to him, he will have no difficulty in applying them to new conditions and in inventing new forms or new modifications. This is what I mean by Scholarship in Architecture. I believe it just now to be the one thing needful. The old days of simple traditional craftsmanship have departed (we have seen the last flicker of them in the "Colonial" period of our own country). Since the fifteenth century, the days of Leon Battista Alberti (the first scholar architect), a new condition has been gradually coming upon us, until now scholarship is the *sine qua non* of our art.

Another point in modern architectural education is of especial importance, particularly in America where we are without examples of the supreme achievements of architecture in the past, and that is the cultivation of that subtle sense which we call artistic taste. We may study architectural history, we may deduce more or less correctly the laws of design upon which the beauty of the old work depends; but all this will not much avail unless our sense of this beauty becomes instinctive, unless we become so sensitive to it that we *feel* whether a thing is beautiful or appropriate long before we can stop to find out why. This invaluable, and for the architect essential, sixth sense is to be cultivated, not only by study and analysis, but chiefly by being constantly surrounded with beautiful things, by forms of the highest artistic quality. A student of architecture, therefore, ought to be surrounded during the whole of his stu-

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dent life with examples of the world's best, and we have to remember that when one is young he is most sensitive to such influences, good or bad. But he will not appreciate these to their fullest, unless he learns to love all fine things, fine music, fine poetry, fine prose, fine painting and sculpture, as well as fine architecture. The more he widens his horizon, the more he appreciates that all these are simply various expressions of the same spirit of beauty and that the same fundamental laws are at the basis of all, the more likely he is to give adequate expression to whatever of real poetic power he may possess and to become, if he has it in him, a poet in stone.

But if he has it not in him to be a poet, he may at any rate learn to produce good, dignified, simple and straightforward architectural prose, without affectation and without bombast, and this is an achievement worth one's whole energy to attain.

These are the ideals in architecture which we try to hold before ourselves at Harvard.

The methods by which we try to work out and apply these principles can only be briefly indicated in a general way. At the foundation of all lies thorough training in the principles of construction. This work is mainly in the hands of the Division of Engineering in courses specially arranged to meet the needs of students of architecture. It includes, besides the essential mathematics, the study of elementary statics, strength of materials and structural design, besides courses in masonry construction, stereotomy, etc.

Beside these a half course for architects on building stones is given in the department of mineralogy.

The courses in the history of architecture extend through three years, occupying three lectures or recitations per week, and include the study of constructive principles, of the laws of design as exemplified in bygone art, and the detailed study of architectural form. The students are required to make illustrative drawings and tracings and to bring in from time to time written reports. Besides these there are included in the curriculum college courses on the history of the fine arts, including sculpture, painting and the minor arts; and courses on the civili-

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LARGE DRAWING ROOM.

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zation of Greece and Rome so that the sources of classic form may be thoroughly understood. There is constant practice in freehand drawing, constant practice in design throughout the curriculum.

In every school of architecture the teaching of design is of course of prime importance. It is sometimes said that design cannot be taught, and in a sense this is true. It is impossible to instil the power of design into one entirely without that gift, The designer, like the poet, is born and not made. But such natural gifts as the individual may possess can certainly be developed and enlarged and given right direction by proper instruction, and in any school of architecture this instruction must properly lie at the centre of the whole scheme. The natural powers which the student may possess must be strengthened by constant practice, by the stimulus of comparison and under the guidance of criticism.

In our scheme of work the study of the orders and the elements of architectural form is begun at once and is continued through the first year and includes some simple problems in design which are given sometimes as brief examples to be worked out in a few hours, sometimes by dictation, or design from description. Indeed the study of each one of the orders is first taken up in this way. After explanation of the function of the orders, the student is led to design the order for himself and afterwards to compare it with the accepted forms. In this way he learns to regard the orders not as rigid and mechanically fixed systems, but as vital forms to be used freely, varying with varying conditions. In addition to this, a series of large drawings is made of each one of the orders from actual examples. Each student under guidance makes his own selection and arranges his plate so as to produce a pleasing effect. This again gives him exercise in composition. He is then ready for the original work in design which begins in the second year and is continued through the remainder of the course. As in most of our architectural schools, the work in design is carried on by means of problems lasting generally a month to six weeks, preliminary sketches are first made occupying a whole

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day undisturbed by other exercises. These are criticised and then the final drawings are developed under the constant criticism of the instructors. Besides this there is continued practice in design from description or dictation, further developing the scheme of the dictation work of the first year. In this way some of the finest works of the masters of the Renaissance are studied. For example the front of the Pandolfini Palace at Florence is described, the students have three hours in which to draw it from this description, using their own best judgment as to proportions and the treatment of detail, and the following week the subject is redrawn accurately so that the student's own rendering of the motive can be compared with the original, side by side at the same scale. In this way the student is led to the most careful study of the best examples, and at the same time to the best kind of criticism of his own endeavors to render similar motives. This work is continued through the subsequent years, the problems increasing in difficulty and complication as the course proceeds.

The work in design is founded upon the study of what is recognized by competent judges everywhere as the very best that the world has produced. A point of departure there must be, and we think it better to found our work on the world's highest achievements, rather than to take as a starting point an imported and debased modern tradition.

While in the latter part of the four-year program practice is given in the use of other historic styles, the work in design is based mainly on the use of the best precedents of Greece and Rome and the Italian Renaissance, as in these comparatively simple forms principles are more readily apprehended and applied and because these forms underlie most of our modern work. But the student is encouraged to use these elements freely and thoughtfully, modifying them to fit the circumstances of each case as it arises.

On the other hand our study of planning and of mass is founded largely upon that of the Ecole des Beaux-Arts at Paris. But here again we admit only what is best. A selection of the best achievements of French architecture and school design is in

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our library and the plates are constantly used. We insist strongly, as do all good schools, on the plan as the foundation of the study of architecture; but we look upon it not as an end in itself — but as a means to producing a convenient and beautiful building.

In addition to the regular staff of instructors, the architect members of the Committee appointed by the board of Overseers take part in the instruction in advanced design. Each member of the Committee in turn has charge of a problem, discussing with the class the conditions when it is given out and a week later criticising the preliminary sketches. The final drawings having been made by the students under the direction of the regular instructors, the final criticism is given by the visiting member of the Committee. This method of work has proved especially valuable and stimulating.

The architects on this committee are Mr. R. S. Peabody, Mr. E. M. Wheelwright, and Mr. R. C. Sturgis, all of whom have repeatedly conducted problems in this way.

In connection with the work in freehand drawing, composition is studied as exemplified in painting and sculpture, so that the laws of design may be seen to apply to these arts also and so be better appreciated in architecture. These courses include work in pencil, pen-and-ink, and water-color.

We think our advantages here somewhat unusual in the close association of an architectural school with the academic department of a great university. This gives us the opportunity to draw upon college courses in our curriculum, and gives students the stimulus of association with men pursuing liberal studies of various kinds. It gives us an atmosphere encouraging to that breadth of interest and that scholarly training which I have insisted upon as essential to the best architectural education. It has the further practical advantage of enabling students while still in the college to anticipate some of their professional work thus making it possible to graduate in architecture two years after taking the first degree in arts.

Having sketched in outline the way in which our work is now carried on, it may be interesting to know the stages of growth since the foundation of the department in the year 1893–94. In

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that year with a view to the establishment of a department of architecture, a single course was given known as Fine Arts 5 with a single instructor and later in the year an assistant. The course was on the historical and technical development of the ancient styles with especial reference to Greek and Roman architectural forms and included much of the work now done in the course on the study of the orders. Twenty-one students took this course, of whom two had the definite intention of continuing the professional study of architecture (they were our first graduates), the remainder being college students. In the following year another instructor in architectural drawing and design was added and that year the curriculum in architecture in the Lawrence Scientific School was really established. In this year, two courses in history were given, one in ancient and one in mediaeval architectural history, a course in elementary architectural drawing, a course in freehand drawing and an elementary course in design. There were twenty-seven students in one of the history courses and five in the other. Twenty-six took the elementary course in architectural drawing, six the course in freehand drawing and four the elementary course in design. Since that time other courses have been successively added until now there are three courses in the history of architecture and three in freehand drawing, one in the elements of architectural form and three in design, one in carpentry construction and one in modelling. Next year there will be added a fourth or post-graduate course in design, a research course in architectural history and an optional course in drawing from the life which will meet in the evening. In 1900–01 courses in landscape architecture were established under the charge of Mr. F. L. Olmsted Jr., in connection with the department. By utilizing courses already established in architecture and courses in the Bussey Institute, the four-year curriculum in landscape architecture was established, which is now in successful operation. There are now one professor, one lecturer, four instructors and two assistants in architecture, and two instructors and an assistant in landscape architecture.

At the present time there are in all, doing work in the depart-

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ment 73 students, of whom 26 are regular students in the Scientific School registered in architecture, 10 regular students in landscape architecture, 8 registered in the college who are anticipating architectural courses in preparation for joining the regular courses later, 4 special students including both architecture and landscape architecture, 2 students who are registered in the Graduate School, and 23 other students registered in the College, Graduate School, and the Scientific School who are taking the historical courses in architecture.

We expect to have next year several graduates in architecture who will be with us for a fifth year doing advanced work. The graduate courses which have been established will be open also to graduates of other architectural schools and to draughtsmen from offices who can give evidence of their fitness to pursue them. The unusually complete equipment we now have should prove especially attractive to advanced students of architectural design. This graduate work has been encouraged by the establishment, by the Corporation, of three scholarships, two in architecture, one in landscape architecture open to holders of the Harvard S. B. in these subjects. In addition those who graduate with credit may compete for the Nelson Robinson Jr. Travelling Fellowship in architecture, which gives the successful candidate one thousand dollars for a year's study and travel in Europe under the general direction of the department. This Fellowship takes the place of the Austin Fellowship withdrawn in order to found the three resident graduate scholarships just mentioned. The first holder of the Austin Fellowship, Mr. E. T. P. Graham, 1900, is still in Europe. The second, Mr. E. B. Lee, '99, will have started for Italy before this goes to press.

In its new building, Nelson Robinson Jr. Hall, which the department has occupied since Christmas, the efficiency of its work in all branches has been vastly increased. The building devoted exclusively to architecture is perfectly adapted to its uses. The equipment has been enlarged until it is already one of the most complete in the country, and it is being further added to as rapidly as is consistent with a wise selection of material.

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NELSON ROBINSON JR. HALL.

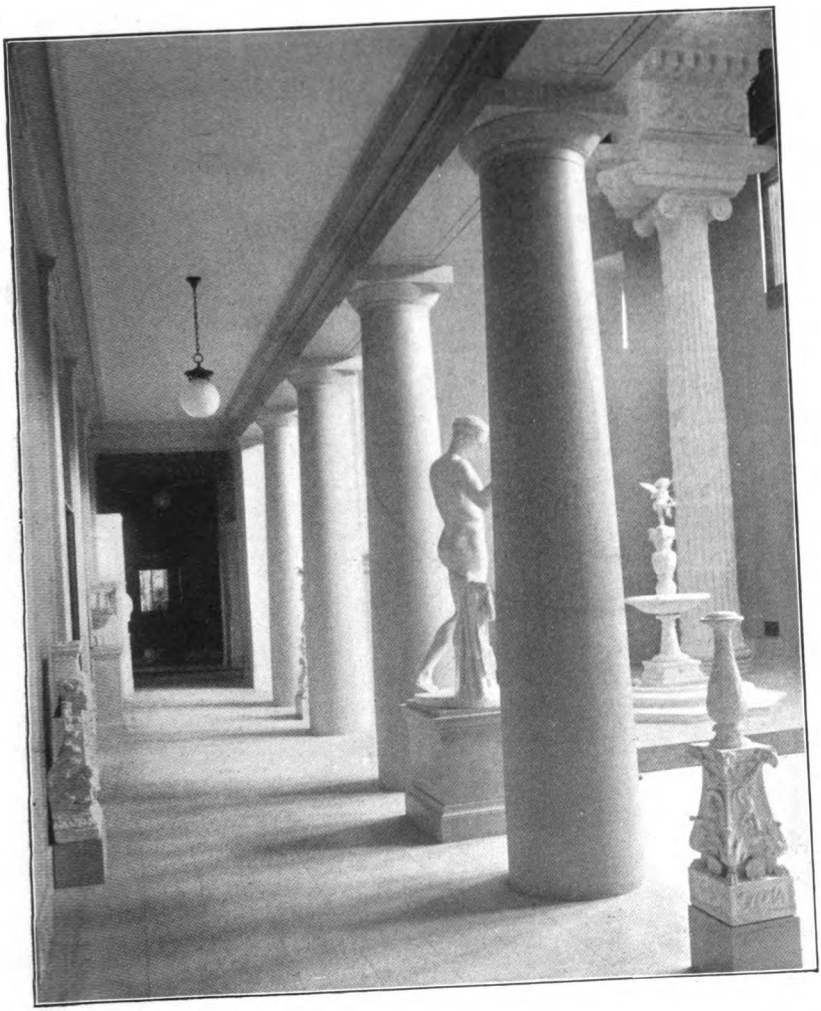
WALTER DANA SWAN.

Instructor in Architecture.

All the classes now in the Architectural Department have worked in the old square building on Holmes Field, the home of the department from the time of its birth in 1893 until January, 1902. The change from these quarters with the dust of their years of service as private residence, geological laboratory, club house and theatre, to the splendid building which forms the subject of this brief description, was perhaps as great a one as was ever made by any department in the University.

The new building finished in 1901, was the gift of Mr. and Mrs. Nelson Robinson of New York as a memorial to their son for whom it is named Nelson Robinson Jr. Hall. He was a member of the class of 1900 in the University and died while in his Junior year in College. The gift of his parents included funds for the building, its equipment, and endowment, and amounted in all to about half a million dollars. Messrs. McKim, Mead & White of New York City were chosen by the Corporation as the architects, and they made the building in its outward appearance conform in its general style with the best structures in the College Yard. Like most of them it has red brick walls laid in Flemish bond, with trimmings of light stone and simple classic details. Its outward expression is that not only of dignity and simplicity but of service, for its large windows imply well-lighted drawing boards, books and casts. To a passerby not versed in these details of the requirements of such a school building its character can be read in the names of the Greek, Roman, Mediaeval and Renaissance architects cut in the stone panels beneath the second story windows, and on the front is a large stone panel bearing the word "Architecture." On the frieze of the west doorway, the design of which is of the character of the

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HALL OF CASTS.

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High Renaissance in Italy, is cut the name of Bramante, the greatest architect of that peroid.

The building is situated in the northeast part of the college yard at the corner of Quincy street and Broadway. It is devoted to instruction in the courses given by the department of architecture, viz.: design, freehand drawing, modelling, architectural history, landscape architecture and building construction. The uses of the building and the completeness of its equipment can best be understood by a description of each room and its contents separately.

One enters by the large south door, beneath a memorial tablet, the Hall of Casts. Here are set up full size casts of representative classical orders to give to the students an idea of that important feature of design,— scale, and the complete Doric, Ionic and Corinthian orders of Greece and Rome can be realized at least in their size and form, if not in relation to the structure of which they are a part.

These large orders occupy at present three of the four corners of this two storied hall and are from the Temple of Theseus at Athens, the Mausoleum at Halikarnassus and the Temple of Vesta at Tivoli. It is planned that a corner of the Temple of Niké Apteros at Athens shall occupy the fourth:

On the western wall is a cast of the balcony from the Cancelleria Palace at Rome and the window enframement in connection with it serves its purpose by enclosing an arch which opens from the staircase into this hall. From the balcony one may look down and see the cast of Verrochio's fountain from the courtyard of the Palazzo Vecchio at Florence, some Greek and Roman capitals or portions of them placed near the ground for more careful study, and also statues, vases and smaller objects. High on the opposite wall, between the Ionic cornice of the Mausoleum and the Roman Corinthian of the Temple of Vesta at Tivoli is hung the great cornice of the Temple of Concord at Rome. The thoughtful design of the larger Corinthian cornice with its consequent multiplicity of parts is compared thus with the smaller and therefore simpler neighboring cornices from Tivoli, and one notes the probable derivation of both from the Ionic type of the Halikarnassus cornice close by.

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The order of the Temple of Theseus is not a cast from the temple itself, hence its regularity of outline in marked contrast to the scars of time on the Mausoleum order opposite. It was built up in cement and staff, from measurements by the best authorities. About the large entrance doorway in this hall is the enframement of the door of the temple of Hercules at Cori, restored in plaster from drawings and data furnished by Mr. E. T. P. Graham, the first holder of the Austin Travelling Fellowship in Architecture. The peculiarity of the lettering of the inscription in the frieze is characteristic of that period of early Roman art which saw the building of the temple at Cori.

The two statues at present in this hall and corridor are casts from the Diadumenos at Delos and the very architectural and almost archaic figure of the charioteer recently excavated at Delphi.

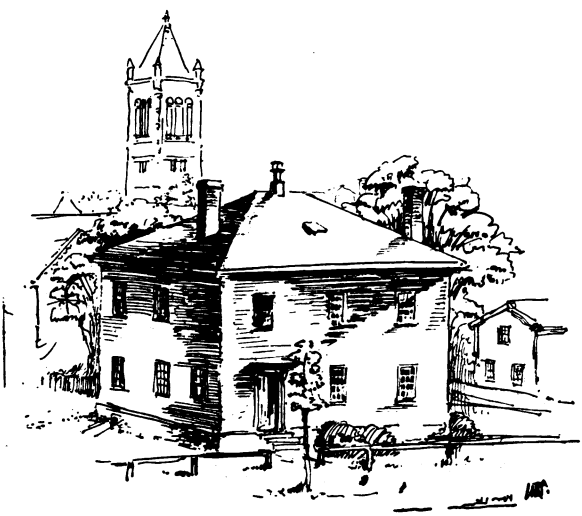
On the central axis of the building and directly opposite the main entrance is the door to the large lecture room having as its enframement a cast of the doorway of the Palazzo di Venezia at Rome. This room is used not only for the lectures in architectural history and landscape architecture for which the two stereopticons in this gallery are the greatest service, but a course in the theory and history of design is also given here. In cases, on the wall are fine textiles, prints and embroideries, illustrating principles. These examples are mostly Oriental in character but on the rear wall under the stereopticon gallery are copies from the works of such old masters as Tintoretto, Carpaccio and Velasquez, and modern work by Degas, Whistler and others. All of these exhibits are loaned to the department by Dr. Denman W. Ross, the lecturer on the course on the theory of Design.

The only strictly architectural features that one observes in this room are the large colored charts of the orders which hang on the north wall and a small cast of the column of the Ionic temple of Niké Apteros in the front corner. In addition to this lecture room there is another and smaller one on the first floor. This has a large blackboard area which is used principally for drill in the elements of architecture, the orders, doors, windows, balustrades, etc., and this as well as the larger lecture room is

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fitted out with small adjustable tables for drawing or writing. The larger room seats 77 students and is in size 31 feet by 53 feet, while the smaller is 31 by 31 and accommodates 42. This room has a rack for charts which can be raised or lowered on the wall back of the instructor's desk.

The freehand drawing room across the corridor from this small lecture room is of the same size, but the change is that from the school room to the studio, for the walls are covered with casts, drawings and paintings. There are also screens on which



Sketch of Old Architectural Building.

subjects are hung from which to work. These can be readily moved so as to gain the best possible light. The tone of this room is mediaeval, for the casts here are of subjects of that period to a great extent. We have here the color of this epoch also, for in the many charming water colors by Mr. Joseph Lindon Smith which hang upon the wall, subjects of Italian, Romanesque and Gothic largely prevail. The collection of water colors and pencil drawings in this room is an especially valuable and inspiring one, including as it does two or more examples of the

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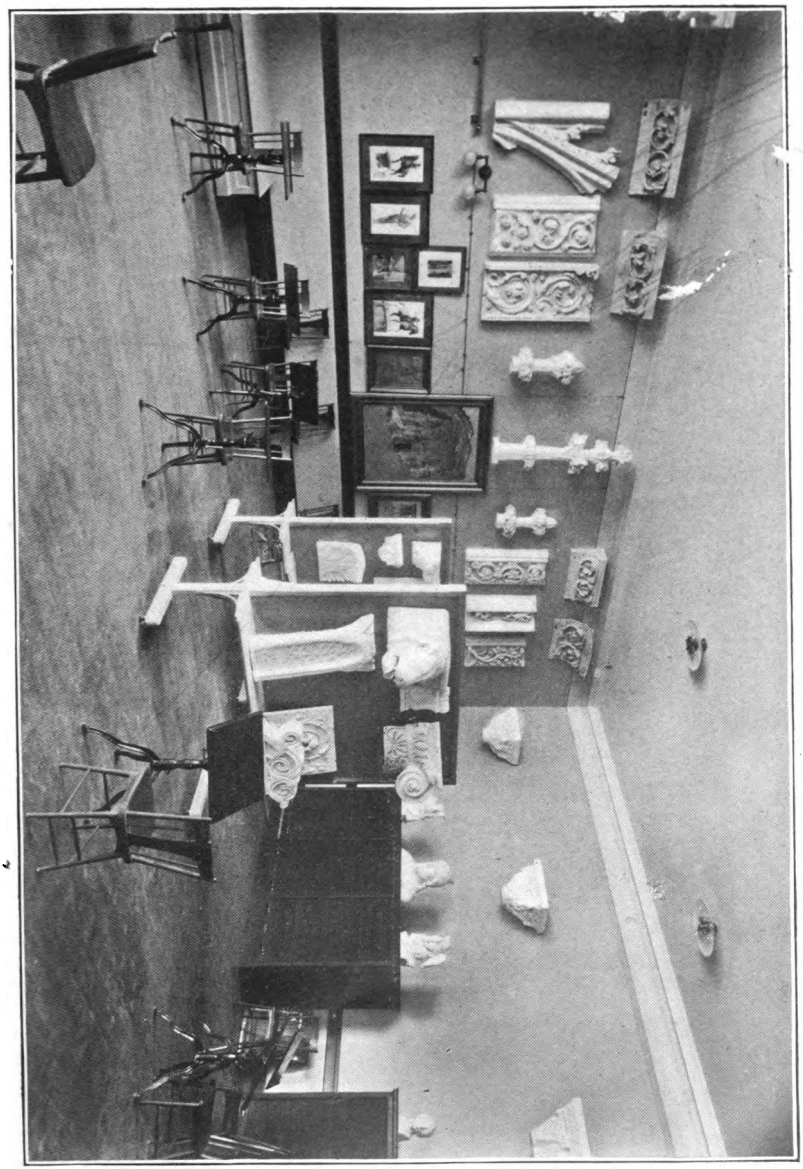
work of each of the following masters: Turner, Girtin, Prout, Harding, Cotman, Cox, Holland, Ruskin and Bunney, as well as a number of fine American works, the majority of which are by J. L. Smith and already referred to. From these water colors the students may work, in many cases, as directly as from the scene or subject itself and some of them also form a basis for the study of method. A collection of prints from Turner's Liber Studiorum plates is very helpful in the study of delineation and composition and photographic reproductions of Constable's drawings serve in the same capacity.

The drawings which do not hang upon the walls are kept systematically in cases prepared for the purpose and in uniform frames as far as possible. There are at present 72 water color subjects, 30 pencil drawings, a dozen pen-and-ink studies and about 50 subjects in different processes such as Cotman's etchings of Normandy. Many of the American water colors and drawings, particularly those by Mr. Smith are loaned to the department by Dr. Ross. The large oil painting by Mr. Smith of the temple of Abu Simbul, in Nubia, which hangs in this room was presented to the department this year by Mrs. David P. Kimball of Boston. In the corner of the room is a model stand for life drawing with an arrangement of the electric fixtures above it to secure the best lighting of the model.

There are here casts of capitals from the tri-forium gallery of Laon Cathedral, Romanesque capitals from Moissac, Gothic finials from Troyes and many other fragments from French cathedrals as well as a few Classic and Renaissance details.

Of these latter there are other examples in the modelling room at the western end of the long marble corridor and here may be found not only such details as may be copied readily in modelling wax but also subjects suggesting composition at larger scale. Among these are handsome details from the Forum of Trajan in Rome and a cast of one of the panels of the door of the Sacristy of the Cathedral of Florence by Luca della Robbia. In the centre of the room are cases containing a collection of pottery largely Oriental in character and the remaining floor space is occupied by the adjustable tables for the work of

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FREEHAND DRAWING ROOM.

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modelling. There are also revolving modelling stands for work with a vertical axis.

Across the corridor is the room used for the exhibition of models of building construction, samples of material, etc., and it is planned to have a very complete display of these.

The glass cases which occupy one side of the room are to be filled with a collection of all the principal building stones, foreign and American and not only the various treatments of the face of the stone will be shown but the instrument for producing such will be exhibited with the specimen.

The tables will be occupied by samples of bricks, models of wood, stone, concrete and iron construction, and other important details of modern building will be shown in a large room in the basement. It is planned to have actual vaults, sections of fireproof construction, as well as portions of brick walls set up in the basement room so that the important details of building will be understood by the students. It is only through the knowledge of the right use and appropriate treatment of material that the effects aimed at in architectural design can be realized.

There are also on the first floor three instructors' rooms and in the mezzanine or half stories over two of them are two rooms, one now occupied by the Pen and Brush Club, an Architectural Society composed mostly of students in the department. The other is a store room for charts, photographic enlargements and such materials for instruction to be used in the lecture rooms.

The coat room is on this floor near the entrance from the college yard and is fitted out with individual lockers of iron cage work, provided with locks which correspond in number to those on the lockers and tables in the drawing room above. Over this and containing the stereopticon gallery is a half storied room devoted to the valuable collection of lantern slides.

The iron and marble stairway to the second story is immediately opposite the entrance to the coat room and is lighted by the arched opening in the hall of casts already referred to in the mention of the Cancelleria balcony. Half way up the stairs a small room for an instructor is conveniently located and the main entrance to the large drawing room is directly opposite the head of the flight.

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Here, 140 feet long and 32 feet wide is the great work room of the department, lighted not only by a long range of windows from the north and others at the east and west ends, but from above. It is equipped with drawing tables which contain both locker and drawers and it will accommodate more than 92 students. Each table has its own electric light fixtures which during the day can be kept entirely out of the way by an arrangement of folding arms. This room has a wainscoting of California redwood 8 feet high, chosen not only for its beautiful color but because it is soft enough to receive thumb tacks for holding studies, tracings, etc., of the students. On the walls of this room are hung fine drawings by American, French and English students and draughtsmen as well as photographic enlargements of classic buildings or their fragments. There are also casts of the Roman orders to make more real to the beginners the details which they usually learn from diagrams.

At the eastern end of the room is a full size cast of one of the panels of the western portal of Chartres Cathedral and as an enframement for one of the doors to the corridor is a cast of the doorway by Benedetto da Majano in the Palazzo Vecchio in Florence.

The Trustees of the Rotch Travelling Scholarship of Boston have lent to the department a number of the envois of the scholars (carefully rendered measured drawings of important European buildings). Many of these hang in the large room and among them are details of the Chateaux of Blois and Chenonceaux, the Ospedale del Ceppo at Pistoja, the Palazzo del Municipio at Brescia, the Pazzi Chapel in Florence, the Ducal Palace in Venice, the Baptistry of San Giovanni in Fonte at Ravenna and the Palazzo Riccardi in Florence.

These are very helpful, not only historically, but in their suggestions for rendering and presenting drawings. Students in the departments of landscape architecture work at one end of the large room and for their purposes there are also landscape plans, sketches and diagrams on the walls.

A smaller drawing room opens from one end of the large room and here are tables where large work, such as perspective

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LIBRARY.

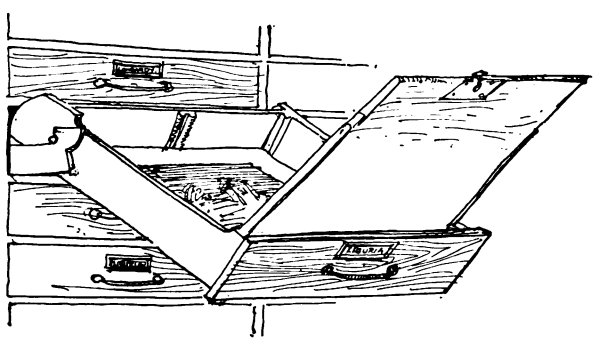
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drawings may be laid out. A class may here be kept by itself for purposes of examination or work "en loge" as the French have it. In this room the criticisms of the problems in design are given and one wall is provided with brass rods on which work to be exhibited is hung.

Among other drawings some full size cartoons in color of certain stained glass windows in Chartres Cathedral are on the walls of this room.

At the opposite end of the building is the library which also opens from the large drawing room so that the students may have the readiest access to books, plates and photographs. By an ingenious system of keeping the latter in small drawers hung



Sketch of Photograph drawer

on slides as shown in the sketch, they can be more easily kept in their proper places, kept flat and at the same time be most accessible to the student. They are classified in their arrangement so as to be of service in the historical courses as well as for references for design, for the latter purpose is fulfilled by a careful cross reference in the card catalogue to subjects and details. This complete system, it is expected, will be in operation before another term. The larger books are kept on sliding shelves with rolling dust proof fronts, and plates of the larger works of reference have been mounted individually and are kept in these cases in portfolios. There are accommodations in this library for

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10,000 photographs and over two thirds of that number are now in the room.

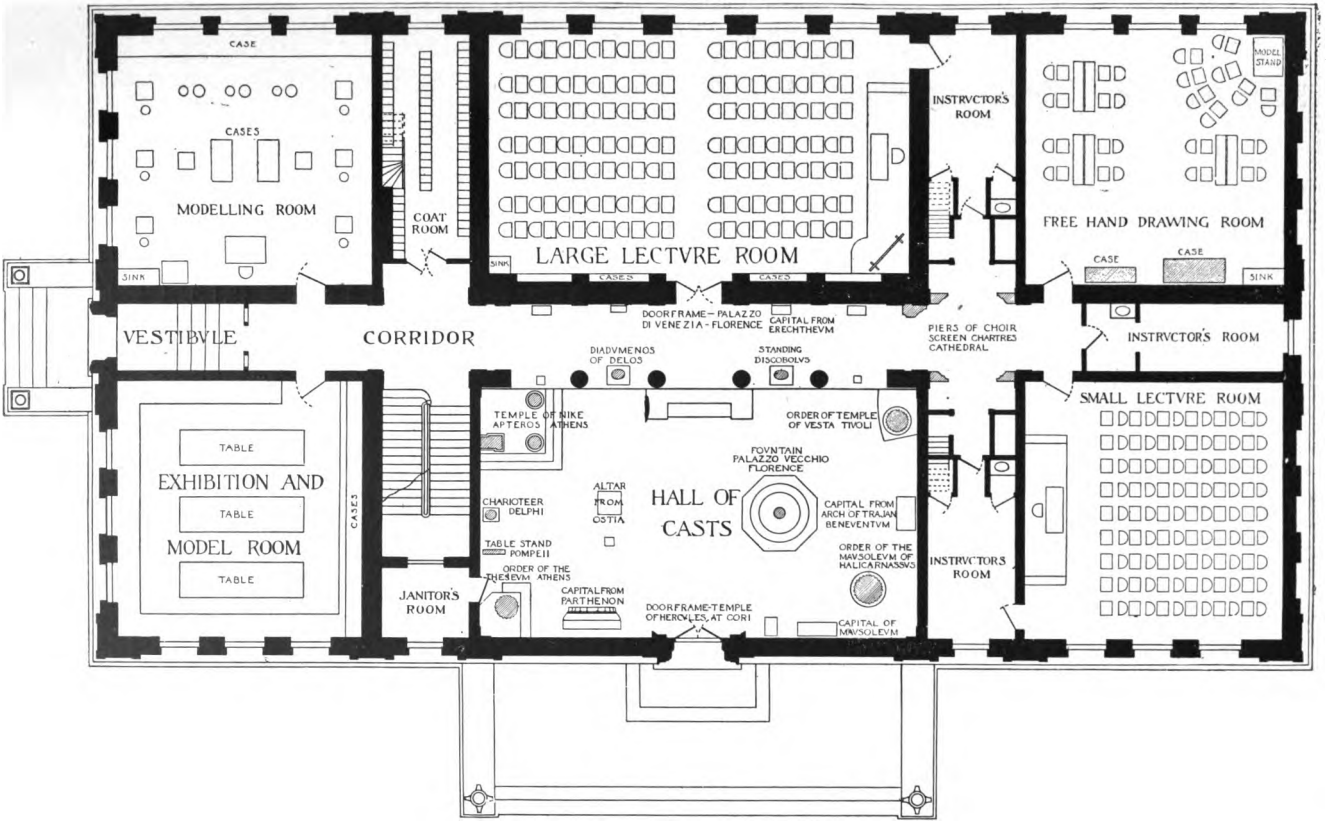
It is planned that the library shall be a strictly working one. There are at present over 400 volumes and there are few that are not consulted in the work of the daily courses. The room itself is handsomely fitted up in dark oak and with its large tables, comfortable chairs, its rugs and pictures it is indeed an attractive and convenient room for study. From one corner of the library opens the librarian's small room and in this story there is also a large instructor's room of the same size as those on the floor below. Over the entrance to this latter room and in the corridor there are casts of portions of the north doorway of the Cathedral at Florence, known as the Porta della Mandorla. There are also other casts on the walls of this second story corridor and the warm and decorative tint of the walls affords a pleasant contrast to the white plaster with its subtle light and shade. This reddish tint covers the walls of both first and second story corridors, while the Hall of Casts has a tone of gray.

The long corridors which run through the centre of the building are separated from the Hall of Casts by colonnades — Doric on the first story and Ionic in the second. Among the large casts which form objects of interest in these corridors are details of the Renaissance portion of the choir screen in Chartres Cathedral which stand outside of the door to the freehand drawing room on the first floor, and another detail of a Renaissance screen — one from a chapel in Laon Cathedral. The latter stands outside the library door at the head of the stairs in the second story.

The basement contains rooms for unpacking, mounting and storing drawings, photographic dark rooms, and a laboratory for topographical work in the course in landscape architecture. There is also a bicycle room near the basement entrance on Quincy street.

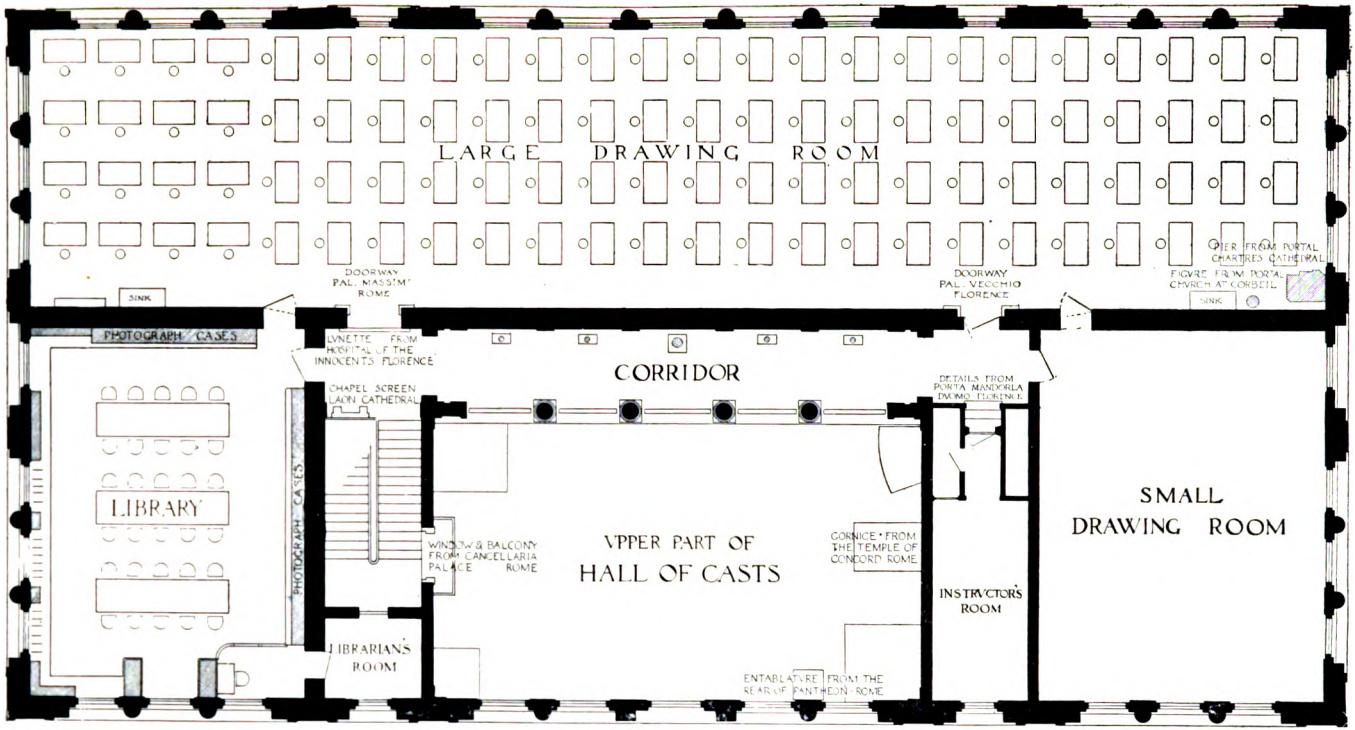
In point of construction the building is entirely fireproof. The system being that of terra cotta wall and floor tiles used in connection with the brick walls and iron beams, with the walls

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PLAN OF FIRST FLOOR.

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PLAN OF SECOND FLOOR.

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covered with what is technically known as hard plaster, and the rooms are ventilated, lighted and heated in the best manner of the time.

The building is an object lesson to the students at work within its walls, not perhaps as the most beautiful structure imaginable for its purpose, but as an example of direct planning and construction, and with one or two minor exceptions, of logical expression of the conditions of the problem given to its architects to solve. The drawings of the buildings might well be used in the class room as expressing a number of the leading principles of architectural composition.

The process of obtaining complete equipment is a slow one, so that it will be some months yet before the original intentions will have been carried out, but owing to the generous conditions of the gift it bids fair to be and should be eventually the best equipped architectural school in the country.

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ILLUMINATING GAS.

WILLIAM ESHORNE McKAY.

(A lecture delivered before the Harvard Engineering Society, Nov. 13, 1901.)

THE subject of artificial lighting is one whose importance to any nation or people is commensurate with their civilization; we wish to prolong the hours of business and of social enjoyment, and we desire to promote morality and to prevent crime. The gigantic influence exerted on the welfare of people congregated in great cities by the continuous supply and use of artificial light can be faintly imagined if we suppose that, at any moment of the night, all the candles, lamps, gas and electric lights in Metropolitan Boston were suddenly extinguished,— to remain so for the rest of the night. Could anything create greater dismay among the respectable portion of the community, or greater rejoicing among the disreputable?

The production of a satisfactory light is an important industry, and the business is of enormous magnitude. England alone requires 11 millions of tons of coal annually for gas-making, and the annual exports of mineral oils from the United States are in excess of sixty millions of dollars. The demand for better and cheaper light has stimulated all forms of manufacture, and in this rapid development gas has not lagged behind. It is only a little more than a hundred years since William Murdoch first lighted his house in Soho by gas. The successful establishment of gas-lighting at the Engineering Works in Soho, where Murdoch was the manager, attracted public attention, and application was made to Parliament for right to supply "the new light" to London. During the inquiry that followed, Murdoch was asked by a prominent member of Parliament, "Do you mean to tell us that it will be possible to have a light without a wick?" "Yes, indeed I do." "Ah! my friend, you are trying to prove too much." Sir Walter Scott made merry over the idea of

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"lighting London with smoke," and of carrying the light about the streets in pipes. Even the renowned scientist Sir Humphrey Davy, said — "Do you contemplate to use the dome of St. Paul's for a gas holder?" One of the cartoons of the period was accompanied by the lines,—

> We thankful are that sun and moon are placed so very high,
> That no tempestuous man may reach to tear them from the sky.
> Were it not so we soon should find that some reforming ass
> Would start, perhaps, to snuff them out and light the world with gas.

While efforts were making to establish the business on a paying basis in Paris and London, Baltimore, in 1816, was the first city to be lighted by gas under the control of a regularly organized company. In 1822, gas was selling in Boston at $5.00 per 1,000 cubic feet. New York began in 1823, with gas at $10.00 per 1,000. In the United States by 1860, 300 companies were capitalized for about $4,000,000 and supplying about 5,000,000 people. At the present time, 1200 cities and towns of the United States are supplied with artificial gas, representing an invested capital of about $600,000,000, and an annual consumption of gas approaching 85 billion cubic feet, supplying nearly 30 million people. The number of premises supplied with gas is at least 2,500,000. In Greater New York the daily use of gas reaches a total of 80 million cubic feet. Metropolitan Boston is perhaps one-fifth of this amount.

For lighting purposes the three principal are coal-gas, oil-gas, and enriched water-gas. Coal-gas is produced by the destructive distillation of bituminous coal in closed retorts. My first knowledge of this form of gas manufacture was received in the lecture room at the Naval Academy, where the text-book on the subject was the Eliot & Storer Chemistry. This book was one of the earlier models created by President Eliot, and the concise and accurate description of coal-gas making could be employed almost without change to explain the process as followed in many existing plants. From the outset it was known that if bituminous coal be placed in an iron vessel, and heat applied externally, the product was a combination of gas and coal-tar, which it was necessary first to cool, then to wash, then to purify

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and then to measure; the same principle holds in the practice of to-day, but the details and the apparatus are entirely changed. The coal is introduced into ⏢ shaped retorts arranged in sets of 3, 5, or more, and heated by a fire of coke or tar. The retorts are of about two square feet cross section, and from 8 to 18 feet long. At first cast iron was used, but this could not endure the high temperatures, and it was replaced by fire-clay, which can stand a higher heat, and stand it longer. Clay retorts, however, were porous, and to prevent the loss of gas through the pores of the retorts the pressure of the gas within the retorts was relieved by the use of the exhauster, or rotary pump. A vacuum in the retort would draw in air, and so spoil the gas, therefore the exhauster keeps the gas in the retort on balance, or at zero pressure. The pipe bringing the gas from the retort is carried below the surface of the water in the hydraulic main (a trough filled with water, and placed across the top of the bench or setting of the retorts). The gas coming from the retort bubbles up through the water, and is drawn away by the exhauster. When the lid of the retort is opened, for charging, the water seal in the hydraulic main makes a perfect valve, and prevents gas going back into the retort. A partial vacuum is maintained in the hydraulic main to counteract the pressure effect of the seal.

The adaptation of the Siemens furnace to heating retorts marked a great advance in gas-making. The primary air supply is heated before passing through the grates, and the secondary air, heated to a very high temperature, effects complete combustion. Efficient regenerative furnaces save one-fourth the coke otherwise necessary; the amount of coal carbonized is greater; more gas is made; the labor is reduced; and the retorts are evenly heated, and last longer.

In the retorts the temperature to which the gas is exposed often reaches 2200° F., but after the gas has reached the hydraulic main it is often less than 150°, and there are then several efficient ways of continuing the cooling, as by surface air condensers, or tubular water condensers, each reduction in temperature being accompanied by the deposition of successive quan-

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tities of tar and water and other liquids. The gas then passes through washers, where the remaining ammonia is taken out. These washers are sometimes cylindrical shells containing many wooden grids that are revolved while streams of water fall over and through them, absorbing the ammoniacal salts. Sometimes they are in the form of tower scrubbers, filled with coke over which the water trickles, taking up a large amount of ammonia compounds. Or they may consist of a series of water seals of slight depth, through which the discharge of the exhauster forces the gas, effectually washing from it the last traces of ammonia.

After this washing process the gas still contains much sulphuretted hydrogen and carbon bi-sulphide. Some coals are very full of sulphur, and in large works a chemist is well occupied to see that the purifiers work properly. The purifiers are rectangular boxes having removable covers. The cover makes a joint with the box by dipping into a water seal of depth sufficient to care for any pressure that the exhauster might throw upon the apparatus. There may be a check purifier of lime, kept in use until carbonic acid shows at the outlet; leaving this purifier the gas would pass through a series of boxes tested for bisulphide of carbon. Finally the gas passes through oxide of iron and parts with its sulphuretted hydrogen. In this country the gas is generally passed through not more than one set of purifying boxes, with several layers of different purifying materials in each; in England it is different, as their coals are more impure, and the restrictions on manufacture are extreme. Purifiers receive much study; some chemists claim that no one knows what goes on inside the boxes. But if the net result is pure gas, made so at reasonable expense, the manager feels that the material purpose is effected, and that the explanation of the process may be postponed. Several things have served to diminish the expense of purification; one of these has been the substitution of oxide of iron, in whole or in part, for lime. One function of the lime was to remove the carbonic acid, this made the gas lighter in weight, and stronger in light. But once used, the lime was useless. With oxide of iron it is different,

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the purifying material can be used repeatedly, being revivified by exposure to the air; it does not remove the carbonic acid from the gas, but the candle power is maintained by the use of oil in the coal-retorts. The next step was to revive the oxide by blowing air through it, without removing it from the purifier. Then, having the engine power of the exhauster ready to force the gas against increased pressure, the depth of purifiers has been enormously increased, and instead of using layers of oxide 6″ or 12″ in thickness, the boxes are now often 6′ or 8′ or even 12′ in depth; this lessens the labor charge.

The gas now passes through the station meter, where the volume is accurately measured and automatically recorded. This meter has a case of cast or wrought iron, and contains three or four partitions that are gauged with extreme accuracy. As the pressure of the gas causes the central axle to revolve, a known quantity of gas is, with each wing of the drum, taken from the inlet side of the meter and discharged at the outlet. It is, as it were, a rotary gas-holder, and is always used with a deep water seal, kept to a fixed level, to insure absolutely correct measure.

After being measured, the gas passes into the gas-holders. These are large steel vessels, the circular sides and domed roof or crown giving the form of an inverted bowl. This is free to rise and fall in a stone, brick or iron tank, filled with water. When the holder is empty of gas it rests on the landing stones at the bottom of the tank; and as gas is forced into the holder, it rises, the gas being held in between the iron of the holder and the water in the tank. The ordinary method of constructing gas-holders is to put up steel columns, against which the guide wheels rest, and which hold the gas-holder steady against the wind. Mechanical engineering has made great advances in the construction of gas-holders. Until a short time ago there were few in the country of a capacity of more than half a million cubic feet. Now holders are built 200 feet in diameter, others are 180 to 200 feet high, when filled. The capacities are now often 5 or 6 million cubic feet. The greatest use of gas usually occurs about dusk; at sunrise and at midnight there is little used. But the process of

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manufacture must be continuous, unless the retorts, and much of the other apparatus, are to suffer, and unless the cost of manufacture is to be almost prohibitive. So the holders give the needed storage room, with leeway to supply the great demand for gas as night falls, and with room to receive the gas made during those hours when little is being sent from the works for consumption.

The gas is not generally sent directly from the holders into the street mains, but is passed by way of a station governor, to control the initial pressure. You can see that if all the burners in the city are lighted there is one pressure that will give the best general service; and with the extinguishing of one after another of those burners, the pressure to keep the supply of gas at the right amount for the remaining burners requires constant attention. As the holder weight is constant (and it is this unbalanced weight that determines the holder pressure), the variations in the street pressure must be minimized by the use of the station governors. Station holders and station governors are frequently placed at other points besides the works, to keep the pressure uniform.

Before leaving the works, a word might be said of the use of machinery for charging the coal into the retorts, and for withdrawing the coke. This machinery, when the magnitude of the works will allow its installation, reduces the labor charge very much. The same is true of handling and purifying materials. Of recent years there have been many installations of inclined retorts; these are set at an angle of about 33°, and the coal is put in the upper ends, and the coke withdrawn from the lower ends of the retorts. There are difficulties incidental to this form of retort, but the decrease in the labor charge is an attractive incentive to the perfecting of the system.

The pipes through which the gas is carried beneath the streets are of cast iron, steel, or wrought iron. In the first case, the pipes are 12 feet long, and they are jointed as are water pipes, by using bell and spigot ends, the space between the iron walls being filled either with lead (as is used with water pipes), or with Portland cement. The cement makes a joint so strong and

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tight that pipes will often part midway in their length rather than at the cement joint. But with lead there is chance for expansion and contraction, to suit summer and winter temperatures; but there is also need for keeping the lead well driven into the joints. When wrought iron or steel is used, the pipes are 18 to 20 feet long, and the joints can be either screw end, with ordinary form of coupling, or they can be made of lead filled into a sleeve that receives the adjacent ends of two lengths of pipe. Drips must be placed at all low points, to receive the condensation, and prevent the pipes from being sealed off. House services are taken off by tapping the main pipe, as in the case of water supply.

After the house service enters the building, the gas passes through the consumer's meter. This apparatus has received so much attention from all sources that any special mention of it might be omitted. It is, however, one of the most clever pieces of mechanism that has ever been invented. Before being set, each meter is tested and certified as being correct by an official appointed in Massachusetts by the State. There is no secret source of power in a gas meter; it is made as nearly accurate as it is possible for a mechanical device to be, and the register cannot change unless gas passes through the meter and moves the hands. The problem is, to move a cubic foot of gas, or a thousand cubic feet of gas, four to ten miles from the point of manufacture, and then to measure it with a loss of pressure of only .1″ to .2″ of water (say 1-250th lb. per square inch), and to measure it accurately at any rate that the chance consumption of the house may require.

To meet the need of a class of consumers that like to buy in small quantities wherever they may happen to be living for the time, and who often make frequent changes of residence, the pre-payment meter was invented. By dropping a quarter, or other specified coin or dummy, into the slot of the machine, the mechanism is released, and the gas can be burned until the meter shows the corresponding amount of gas to have passed. The supply is then automatically shut off, unless additional coins are placed in the slot. These pre-payment meters gave a

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great impetus to gas consumption, and they are now used everywhere in large numbers. The demand for them has, at times, exceeded the capacity of the factories engaged in their manufacture. In four years, two of the London gas companies set 100,000 of these meters, and reported that they were collecting two tons of coppers per day from the cash boxes.

With intelligence, good gas can be economically made and distributed, but its use at the burner depends upon each consumer, and this is the most important point in the gas supply. Gas companies recognize this fact, and co-operate with the public in keeping the burners in order. While the ordinary burner, using four cubic feet of gas per hour, will give a good light, yet the same burner can be made to pass 8 or more feet per hour, yielding less light with each increase in gas used, if the burner is clogged with dirt or dust, or otherwise handicapped.

In 1885, Dr. Auer, an Austrian scientist, made known that he had discovered and invented a mantle by which a light of great power could be made with the use of a less amount of gas. After some years this invention took commercial shape, and the Welsbach light became the fortunate ally of the gas industry. In this light, a bunsen burner gives the heating flame that brings to incandescence the superimposed mantle. The mantle is woven of cotton, and is saturated with rare earths that experience has selected as the best and most durable under the described conditions. When the original mantle of cotton burns away, the remaining earths retain the form thus given. Thus 2.5 cubic feet of gas will furnish 60 candle-power light per hour. The luminous glory of this achievement startled even the ultra-conservative Austrian Government into recognizing its son, and Dr. Carl Auer was ennobled, becoming "Von Welsbach." This light gave to gas companies that street lighting that had been invaded by the arc and incandescent electric light, and gave the world the highest candle-power for the least cost that has yet been produced. In this country we have not an idea of the universal employment of the Welsbach that can be seen everywhere in Europe, for house, street and store, and for decoration upon occasion of civic festivities.

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In the manufacture of coal-gas a considerable part of the cost is recovered from the sale of the residuals. One ton of coal will yield 10,000 or more feet of gas, 20 to 25 gals. of weak ammoniacal liquor (equivalent to 30 lbs. ammonium sulphate), 13 cwt. of coke, and about 12 gallons of tar. The sulphate is a valuable fertilizer, and when the ammonia is not thus disposed of it is put on the market in other forms, as aqua ammonia, etc. The 12 gallons of tar yield 1.1 lb. benzine (or 1.1 lb. aniline); .9 lb. toluene (or .62 lb. magenta, or 1.2 lb. methyl-violet); 1.5 lb. phenol; 6.3 lb. naphthalene; 2.4 lb. solvent naphtha; 2.4 lbs. heavy naptha; 17 lbs. creosote; .5 lb. anthracene (or 2.25 lbs. alizarine), etc., besides lubricating oils, lampblack, pitch and coke. The wonderful work with coal-tar colors and products reads like a fairy tale. The finest paintings are often with coal-tar colors; the most beautiful silks and other fabrics are dyed with these extracts; and remarkable assistance to medical and surgical science has come from the employment of the derivatives of coal-tar. The coal-tar genealogical tree is longer than any that I find exhibited in the historical rooms, and it is fully as useful.

The market for the residuals of coal-gas manufacture has led to the construction of coke-ovens. In this form of apparatus the coke is the immediate aim of operating, and, with the ammonia and tar, this yields the prime net returns. But the heating of the retorts is done with a part of the gas from the coal coked, and the remainder of the gas becomes a residual by the sale of which the enterprise is benefited. In this construction, the retorts are nearly rectangular, of dimensions inside 6′ high, 18″ wide, and 33′ to 44′ long. The charge for one of these enormous retorts is six or more tons of coal, and the time of coking may be extended to 48 hours, so that the coke thus made will be very hard, and fit for metallurgical purposes. These coke-ovens have long been successfully operated in Germany in connection with some other establishment, as an iron or steel plant. A very large plant of 400 ovens has been erected in Massachusetts, at Everett, and gas from this source is now being supplied to neighboring cities. Coal-gas is usually enriched by using a half gallon or more of oil per 1,000 cubic feet; this oil is intro-

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duced into the retort with the coal, and in this way the result is a fixed or permanent gas, or mixture of gases, of 18 or more candle-power. With coke-oven gas, the first fraction, having high candle-power (19 or 20), is used for illumination; and the remaining fraction, of much lower candle-power, is used for heating the ovens or retorts.

The Welsbach mantle gives high candle-power independent of the gas used, but the public is not yet educated to the universal use of these mantles. The laws of Massachusetts require that the candle-power of the gas, as tested with the burner best adapted for it, must be not less than 16. Other requirements limit the sulphur and ammonia that may remain in the finished gas, and prohibit any sulphuretted hydrogen. Compliance with these statutes, and examination of the constituent gases and of the coals, oils, and residuals, calls for considerable analysis and photometric work. After the coal is put into the retort there is nothing to be seen of the products that result in the light at the burner; analysis is effected by bringing a sample of the gas into contact with solutions and chemicals that successively absorb components that experience has shown will be present in some proportion. Thus, caustic potash absorbs the carbonic acid, the amount or proportion being determined by burette or pipette measurement before and after contact with the reagent. Then sulphuric acid takes out the illuminants. The carbon monoxide is absorbed by cupric chloride; the oxygen by phosphorus. The remainder of the analysis is too complex for description here. The candle-power is found by burning a specified volume of gas at a stated rate, and also burning a candle of prescribed form, volume, density and material, with such a wick that the rate of burning is also defined. The relative intensities of the lights thus made are measured on a movable screen, and the value of the gas, in candles, determined directly. Other means of measuring the light are by use of Methven Screens, Edgerton Slots, Pentane Lamps, etc., all of which are referred first to candles, or standardized by candles. In Massachusetts, the gas is burned at the rate of five cubic feet per hour, and the candle is of sperm, to burn at the rate of 120 grains per hour, the test may

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be made in from five to fifteen minutes. The tests for sulphur and ammonia also require much time, skill and care.

In 1794, when the French Revolution was seeking material for the guillotine, the Chemist Lavoisier was seized and hurried away to execution. On his way to the scaffold he begged to be allowed just one more day of life, that he might give to the world the secret of an important invention. This request was refused, and an examination of his notes, with the aid of present knowledge, has shown that he had discovered the principle of the manufacture of water-gas. No one made use of the work of Lavoisier, and it was not until the civil war in America that the subject became of interest. In 1861, an aeronaut journeyed from Cincinnati to Savannah, one thousand miles, in ten hours, and by this feat recommended himself to President Lincoln, who then appointed Prof. Lowe as the head of the Bureau of Observation of the army in the field. Lowe made many hundreds of ascensions, and the need of a quick, cheap, and easy manufacture of a buoyant gas, preferably hydrogen, engaged his study. He finally found that by passing steam through a bed of coal or coke heated to incandescence, the steam was in part decomposed, yielding hydrogen and oxygen; then the nascent oxygen united with the incandescent carbon, forming carbon monoxide. This was the beginning of water-gas. The gas thus made is light in weight, and without illuminating power. The opportune development of the petroleum industry furnished the material with which the water-gas can be enriched effectively, the resultant gases being permanent, odorous, and of excellent value for light and heat. As at present manufactured, the apparatus for water-gas consists of three cylindrical shells lined with fire-brick, and connected by mains of large area for the free flow of the gases generated. The first shell contains the anthracite coal or coke; this is called the generator. The second shell contains loose fire-brick laid in checkerwork, and is the carbureter; the third shell also contains loose fire-brick, and is the superheater. The three chambers have provision for supplying air under pressure. The coal is raised to incandescence by a powerful forced blast, the blast gases then passing into the

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other two chambers, where auxiliary air supply is introduced, completing the combustion of the blast gases, and heating the fire-brick to a high temperature. The air-blast is then shut off, and steam is admitted beneath the coal; this makes a large volume of water-gas as already explained, which passes into the carbureter where the enriching oil is now introduced. The oil-gas and water-gas together pass through the carbureter, and super-heater; the oil is broken up or down into lower compounds, and the enriched water-gas issues from the super-heater as a mixture of gases of great permanence and high illumination. The period of gas making cannot well extend beyond ten minutes, as the heat of the coal and of the fire-bricks becomes exhausted, and another period of blasting must follow. Water-gas is made to burn, either for light, or for heat or for power; when thus used, the products of combustion are more satisfactory than are those of coal-gas. There is scarcely a trace of ammonia in water-gas, and the sulphur compounds are present in much smaller quantities than they exist in coal-gas. The combustion of sulphur compounds gives sulphuric and sulphurous acids that bleach and rot organic tissues, and are very undesirable to breathe; it is for these reasons that engineers desire to remove these impurities from illuminating gases; and as they occur in exceedingly small amounts in enriched water-gas, the purification of that product is much easier, and of more thorough accomplishment than in the case of coal gas. The distribution of water-gas is nearly identical with that of coal-gas; being heavier, it requires larger mains to deliver a like amount under the same pressure.

Oil-gas is the product of the distillation of petroleum or of a distillate of petroleum. It is a heavier gas, of higher candle-power than either of the other illuminating gases. The lighting of railway trains with Pintsch gas is an instance of the excellent adaptation of oil-gas to illumination. Its manufacture does not differ in principle from the processes already described, the oil being introduced into small cast-iron retorts, and converted into gas by the external firing of the benches. Compressors compact the gas into the small cylinders beneath the railway carriages,

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and the points of manufacture are so distributed that the supply suits the travel of the train.

Acetylene gas has, as yet, hardly gained sufficient footing to be recognized as a competitor of the foregoing. The carbide of calcium from which it is made is expensive, and the gas is unstable, and not without special dangers, as has been shown by the many unexplained explosions that have followed in the wake of its use, all over this and other countries. The towns of South Hadley and Marion, in Massachusetts, are supplied with acetylene gas.

Natural gas is geographically an historical vanishing phenomenon. Owing to its lack of illuminating properities, its greatest use has been for heat and power; the Welsbach mantle has made possible the utilization of the high heat value of this gas for lighting purposes. The engineer here deals with different conditions from those usually circumscribing the gas supply. The gas issues from the earth under a pressure that is often in excess of 300 lbs. To reduce this to nearly 1″ of water pressure (or about 1-30 lb. pressure), at the burner tip is a tribute to invention. The transportation of natural gas under high pressures, for long distances, is conveniently accomplished by use of pumps run by gas engines, taking their supply from the material they pump. The development of the gas engine has been steady and sure, engines of more than 1,000 h. p. are now in operation with excellent and economical results.

The use of gas for heating and for power now rivals its use for lighting. For the maker of gas, this is an advantage, as the use of gas for purposes other than lighting generally occurs at times that are not the periods of maximum demand for illumination. Thus, the manufacturing and distributing plants are in more nearly continuous service at a larger percentage of their capacity. It is noticeable that companies have of late years devoted much effort to enlarge the use of gas for heat and power. As a direct consequence of this work, and of the ever increasing use of Welsbach mantles for lighting, it has come to be a practice to regard more closely the heat evaluation of the gas supplied. And it has been frequently proposed of late to substitute

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the calorimeter for the photometer in a statement of relative values, or in standardizing. A cubic foot of gas has a calorific value of 600 to 700 B.T.U.; in the case of natural gas the value is 1,000 to 1,100 B.T.U.; and some gas supplied in Massachusetts has tested and computed over 1,400 B.T.U.

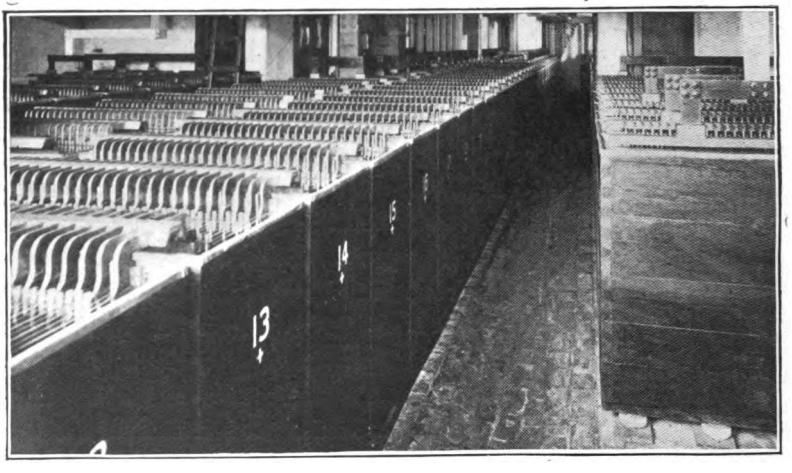
Forty years ago, it was thought that any one could make and distribute gas, that there was no need of particular knowledge or skill, that the coal was to be put into the retort, cooked, and the issuing gas was ready for service. Now, all that is changed. Each year sees the industry receive fresh bands of graduates from technical schools, each decade has been marked by splendid progress, the outcome of scientific investigation and the application of learning. Societies of engineers engaged in the industry have effectively advanced the profession; the oldest of these is the New England Association of Gas Engineers; this was followed by the Guild of Gas Managers, also of New England, by the American Gas-Light Association with a present membership of nearly 700, the Western Association, with a membership of nearly 500, and by several others. The effect of the transformation from the corps of uneducated men to the body of highly trained observers, and intelligent inventors and adapters, that come from the Technical Colleges, is very marked. Stevens Institute has long maintained a thorough course in gas engineering, and the men graduated with credit in this department are in great demand; one large corporation, the United Gas Improvement Company, has often taken all that were available. The Institute of Technology, Boston, has a course in gas and oil analysis. There is hardly an accepted type of retort, or furnace, or process, that has not a location and service in some one of the cities or suburbs immediately adjacent to Boston. The results of the general education of the profession speak encouragement: 80 years ago, gas cost $6 to $10 per 1,000, was full of impurities, uncertain in supply, and of not more than 12 candle-power; to-day, it costs $1 per 1,000, is pure in quality, unfailing in supply, and, with the Welsbach mantle, reaches 80 to 100 candle-power for the same consumption of gas that formerly gave only 12 to 14 candle-power.

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STORAGE BATTERIES — II.

PHILIP WHITNEY DAVIS, A. B. '93, S. B. '95.

THE largest storage batteries are those operated by the so-called Edison Illuminating Companies in the large cities of the country. The first central stations of these companies were



LARGE LIGHTING BATTERY.
Capacity for peak load, 8,000 lamps.

generally situated in the heart of the city, close to the business district. The greater part of their load was, and still is, in lights for offices and stores, where a great deal of light is used for a very short period of time. The heavy line in figure 1 shows a typical daily load curve from one of these stations. It calls for over 70,000 lights between the hours of 5 and 6.30 P. M.; and if the entire load were to be supplied by engine capacity alone, roughly speaking, machinery capable of supplying 25,000 lights would remain idle for twenty-one hours. The loss

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that this involves is not merely the interest and taxes on the cost of this machinery and the land it occupies, — it also means expenditure for attendance, coal, and supplies which produces

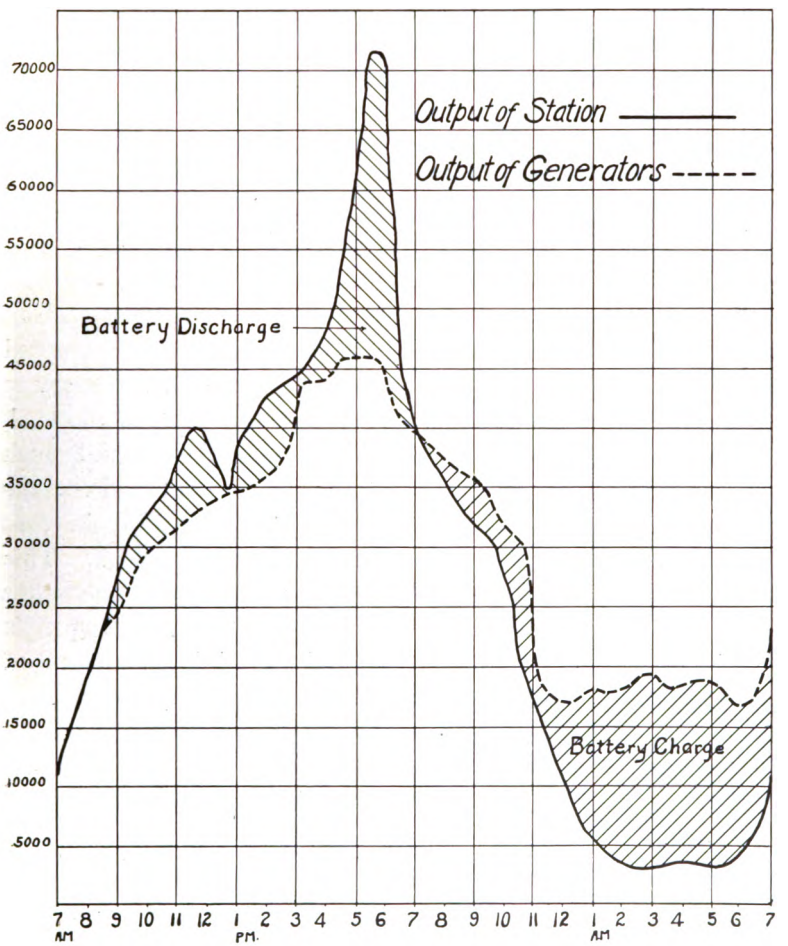


FIG. 1.

no revenue. Engineers and firemen for this machinery which operates only two or three hours per day cannot be had for that time at a proportionate decrease in wages, nor can the fires under

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the boilers be proportioned to the short time that the machinery is under steam. The dotted line in figure 1 shows the load as it was actually generated. A part was stored in a battery at night and distributed later as required, the heaviest discharge taking place between 5 and 6.30 P. M. on the following day. The cost of the battery, for a sharp peak like this, is about the same as that of the machinery it displaces, but the saving in operation and the security obtained against interruption of the service are the features that make it valuable. It is usually the practice to "float" the battery system on the bus bars and use it as a regulator, as much as possible. No matter how the steam generating system is divided up, it is difficult, without the aid of a battery, to follow the load with machinery in operation so as to secure at all times a reasonably economical load for the steam engines. The service of a large city demands uninterrupted supply at all times. On this account it would be necessary to keep under steam, machinery for which there would be no load, in order to respond to any sudden increase in demand, such as occurs often in summer when a heavy cloud darkens the shops; or again merely to maintain an existing load in case any of the remainder of the machinery becomes disabled. This work is admirably performed by the battery which, as one writer has expressed it, becomes "the watch dog of the company's service." At the same time it permits a minimum amount of machinery to be kept in operation, any difference between the capacity of this machinery and the actual demand being made up by charging or discharging the battery as circumstances require.

The value of storage batteries as insurance of continuous operation under unexpected and trying conditions has been repeatedly put to the test, and an instance or two will illustrate how this may happen. In January last in the plant of a large western lighting company, where energy is transmitted from a water power plant to a sub-station, a high tension cable was burned out, throwing a load of 16,000 lamps on to a battery which carried it until an old disused Edison plant and some alternating machinery could be started up. With this help the battery further carried the service successfully through the

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evening peak load; whereas without it an interruption of two hours duration would have occurred. Again, during the same month, in the station of another company, a cylinder head of an engine driving an exciter blew out leaving a large alternator helpless. A battery at a substation stepped in for five minutes, reversing its rotaries, and kept things operating until another machine could be put into commission, thereby preventing an interruption to the service. On a third occasion, in a large eastern company's main power plant a main steam pipe expansion joint broke just at the time of peak load, causing a complete shut down of the plant on account of the escaping steam which filled the station. The battery system with the help of what machinery could be started in other stations carried the whole load of the city for some time.

A battery equipment is often divided into several plants located at favorable centres for distribution. In this way considerable saving in the copper required to cover a given territory is effected. The energy for the peak of the load is transmitted to the substation batteries at a slow rate during the greater part of the day and discharged by them rapidly when needed. Taking a specific problem, suppose 1000 lamps are situated one mile from the generating station and that they are to be lighted for a period of two hours, the line loss being 10%. If, instead of feeding out this whole energy of 2,000 lamp-hours in two hours, we feed it out in ten hours (by aid of a battery located near the lamps), the current will be one-fifth as great; consequently, for the given line loss of 10%, the copper required will be one-fifth as great.

Where very large areas are to be covered, as in New York and Brooklyn, the advantages of having the steam plant concentrated at one spot advantageously situated are retained by using high tension alternating current for distributing energy to battery substations where it is transformed to direct current by rotary converters and stored in batteries during light load periods. In cases where the substations come in residential districts the peak is broad and not sharp, being so long in duration that the cost of a battery to take the whole of it is prohib-

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itive. Yet, a battery in the substation by discharging during the hours of the business peak, is just as effective in relieving the main station as if located therein, because the main station may furnish to the business section the power which it would otherwise be called on to supply to the residence substation. By locating the battery at the substation a factor of safety is provided for the service and attendance may be reduced at times of light load, though of course there is no saving in transmission line or substation investment.

In order to gain a proper understanding of this subject it would seem necessary to describe some of the mechanical and operating details. The batteries are located in well ventilated rooms cut off from the rest of the station. The labor needed consists in daily inspections of the cells to make sure that they are operating properly. Readings are taken on the specific gravity of the acid and on the voltage of each cell; and records of charge and discharge are also kept. As the water evaporates from the surface of the liquid more is added in order that the plates may not become exposed to the air. The attention of one man one or two hours a day is amply sufficient to keep everything in proper shape; the remainder of the time there is no one in the battery room. Each cell develops a pressure of about two volts or less according to the rate of discharge and this pressure gradually drops to 1.8 or 1.7 volts when the battery is fully discharged. It follows that, if 120 volts pressure is required at the bus bar, sixty cells will be put in series at the start. But the pressure maintained by these sixty cells will gradually fall as the discharge proceeds, ending at 102 volts. This drop cannot be tolerated, and, in order to compensate for it, fresh cells are added to the circuit from time to time, until at the end of discharge there will be about seventy cells in circuit. The cutting in or out of circuit of these "end cells," as they are called, is done at the switch board by a special switch provided with a sliding brush which picks up the current from any one of a number of contacts. These contacts are connected each to an end cell by a copper conductor of sufficient cross section to carry the whole current from the battery. The brush is actuated

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by a worm driven either by hand or by a motor controlled from a distance, in case the switchboard room is not located conveniently to the battery room. By providing several end cell switches connecting to the same end cells, current may be taken from the battery at several different pressures. This is a valuable feature for keeping feeders of different lengths fully loaded under different conditions of the demand and thereby maintaining a more uniform pressure at the distributing points. The division of load between battery and machinery is controlled by balancing their voltages, a very small change in voltage being sufficient to alter the load distribution materially. The battery will readily discharge at any rate, as has already been explained, owing to its low internal resistance. The higher the discharge rate the lower will be the effective voltage per cell and the greater will be the number of end cells required.

The discharge rate also affects the duration of the discharge in a remarkable way. It is found experimentally that doubling the normal eight hour rate exhausts a cell in three hours instead of in four as might have been expected. Again doubling the rate, i. e., making it four times the normal, is found to exhaust the cell in one hour instead of in two. This apparent loss in time capacity with increase in the rate of doing work does not, however, mean an energy loss. A cell which requires eight hours at the normal rate to fully charge it and appears to be fully exhausted in three hours by a discharge double the normal rate, can be fully restored by the normal rate of charge continued for only six hours. Moreover, the capacity not available at the high rate of discharge is restored if the rate be reduced; and, given sufficient time, the cell goes on discharging until there is no more unconverted active material on the plates.

Towards the end of charge, the battery voltage rises rapidly until it reaches 2.5 volts per cell; and, on this account, it would not be possible to fully charge a battery from the ordinary bus pressure, since sixty cells would require 150 volts. To meet this requirement the current for the battery charge is passed through an auxiliary shunt wound motor-driven dynamo, called a "booster," which adds the required pressure.

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In general, the conditions surrounding large plants which supply the great cities with light and power differ only in magnitude from those of many smaller plants. Wherever power is generated for electric light there is usually a variable demand which makes the opportunity of the accumulator. Office buildings, apartment houses, country residences, mills, and factories offer situations where it is a useful and sometimes indispensable auxiliary. Many of the large office buildings in cities have very complete power plants. Here the function of the battery is twofold, it being used as a regulator and as an accumulator for peak loads. During the day the load is chiefly from elevators and is characterized by extremely sudden and heavy fluctuations, which are greater than the engine governor can success-

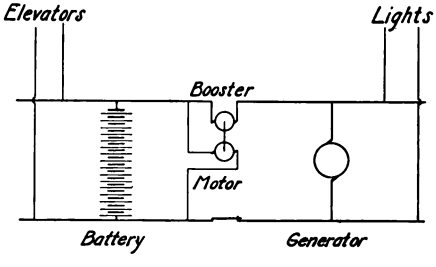


FIG. 2.

fully meet. The result is a drop in speed with corresponding drop in voltage, manifesting itself by a very unpleasant flickering of all the lights that may happen to be burning in the building. To avoid this two separate engines would have to be operated, one to carry the lights, the other the elevator load. Throughout the day the average load is light compared with the evening peak, and dividing it between two engines scarcely improves a situation already bad as regards economy.

The method adopted for securing regulation with the battery, so that the entire load may be furnished by one machine is very ingenious. Two sets of bus bars are provided, (see figure 2), one being supplied directly from the generator and the other

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from the storage battery. The lights are taken from the generator, or lighting bus as it is more often called, while the elevator and all variable power demand is taken from the battery bus. The two sets of bus bars are connected together through a "constant current booster" on one side. This machine is a small motor-driven dynamo which transmits from the lighting bus to the power bus a nearly steady current equal to the average demand upon the power bus. The battery cannot take the fluctuations thrown on the power bus by the elevators without dropping its voltage, because of its internal resistance. If the pressure of the power bus is permitted to drop in order to allow the battery to step in and take the load there is at once a tendency to transfer current to it from the lighting bus. This tendency is counteracted by the booster which is wound differentially so that any small increase in the current passing through it causes it to develop a pressure opposing the passage of the current. Thus a small increase, say 5 or 10%, may be all of the fluctuation that reaches the dynamo, the battery furnishing the other 90% and dropping its own voltage 5 or 6% while the dynamo voltage remains unchanged.

Besides the functions of regulation and peak discharge exercised by the battery, it also provides for the night lights, the steam plant being entirely shut down and no labor being required to look after the battery. This last feature is of the greatest importance to the small user of current. In country residences, where light may be needed at any time all through the hours of darkness, it would be out of the question to operate the gas engine or steam plant all night. In general, the improvement in the load factor and the greater flexibility secured by the introduction of the storage battery into isolated plants results in a large saving in cost of operation. In some cases, a saving of one third of the coal bill has been shown to be possible.

The trolley roads of the country call for more electric power than goes to any other use and the demand is also of a more variable nature than in any other service excepting elevator work. It is not surprising, therefore, to find that the applica-

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tion of the accumulator to railways is increasing rapidly. The operation of individual cars by the accumulator battery was among its first applications, the object being to provide a self-contained power unit able to travel on any track and so do away with overhead wires. The weight and the expense attached to the operation of the battery in this service have, however, worked against an extension of its use, although there are lines now in successful operation where the traffic warrants the expense and the cheaper trolley is barred by municipal regulations. In recent years storage battery development has been as an auxiliary to the trolley road, being installed in the power stations or out on the line according to the conditions to be met.

The object in either case is to even up the fluctuations which are inseparable from all ordinary trolley roads and, by the elimination of this feature, to make savings in the cost of operation or in first cost. Figure 3 shows three curves of readings taken in a railway power station during a period of eight minutes. The upper curve marked "total station load" is a typical railway load curve. It will be observed that this load averages about 170 amperes but reaches maximums of nearly three times that amount and often dies away to nothing. If we suppose the machinery to be capable of standing safely momentary overloads of fifty percent, this load would call for the operation of a 180 K. W. unit. A battery was installed in this plant, and the second curve shows its performance. The bottom curve shows the work done by the generator. The latter averages only 115 amperes or 63 K. W. while the load averages 93 K. W., the difference of 30 K. W. being furnished by the battery in addition to the fluctuations. The sum of the battery discharges exceeded the sum of its charges as is evident from an inspection of the curve. This was possible only because, at a subsequent period, perhaps the next eight minutes, the load average was below 63 K. W. and the battery then recovered the lost charge.

We are able, then, to substitute say a 75 K. W. unit operated at 80% of its rating and a battery of 200 amperes or 115 K. W. capacity overloaded occasionally 50% for a 180 K. W. unit which would have to be operated at a load never exceeding an

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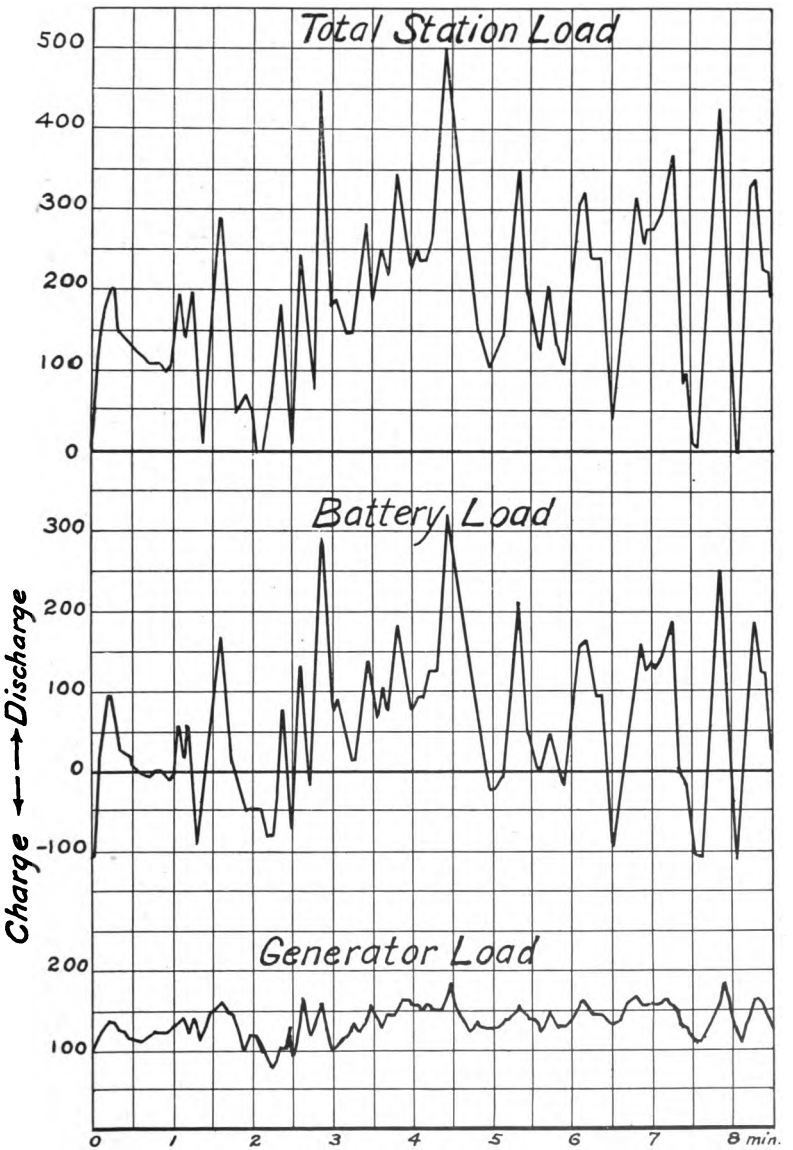


FIG. 3.

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average of 35% of its capacity, though occasionally reaching a momentary overload of 50%. The cost of a storage battery is approximately the same as the cost of machinery, rating the battery on the hour rate of discharge, so that the first cost of the two plants is about the same in either case. But the operating expenses would be very different. In the one case we have an engine loaded to 35% of its capacity taking 6 lbs. of coal per K. W. hour, in the other the engine is loaded to 80% of its capacity and can therefore furnish power for 4 lbs. of coal per K. W. hour, the saving being 2 lbs. of coal. Such a plant would probably put out 400,000 K. W. hours in a year, so in that time the saving would be 400 tons of coal, costing $4.00 a ton, or $1600. In addition the engine and generator operated with the battery are not subjected to the terrific shocks which must be endured by the larger unit operating alone. The battery makes it possible to maintain power at the trolley wire twenty-four hours a day without operating machinery late at night.

Figure 4 shows very clearly how the operation of a railway plant may be changed by the introduction of a battery. Curve A is a daily load curve from a railway operating fourteen cars in a small New England town. The curve shows the change in average load from hour to hour and does not show the rapid and violent fluctuations taking place from moment to moment as the eight minute curve in figure 3 does. The actual readings varied continually above and below the average values shown by from 300 to 500 amperes, but any attempt to show these on so small a scale would simply result in a broad band of ink since readings taken every five seconds would call for 17,000 readings in the space shown. These fluctuations causing the load to reach 1,000 amperes momentarily compel the operation of machinery of capacity as indicated by the broken line. The generating machinery of the station consists of four 100 K. W. units equal to 725 amperes normal output at 550 volts, and all four as shown by the curve are in operation between the hours of 11 A. M. and 11.30 P. M., leaving no reserve in case of an accident to one of them. The introduction of the

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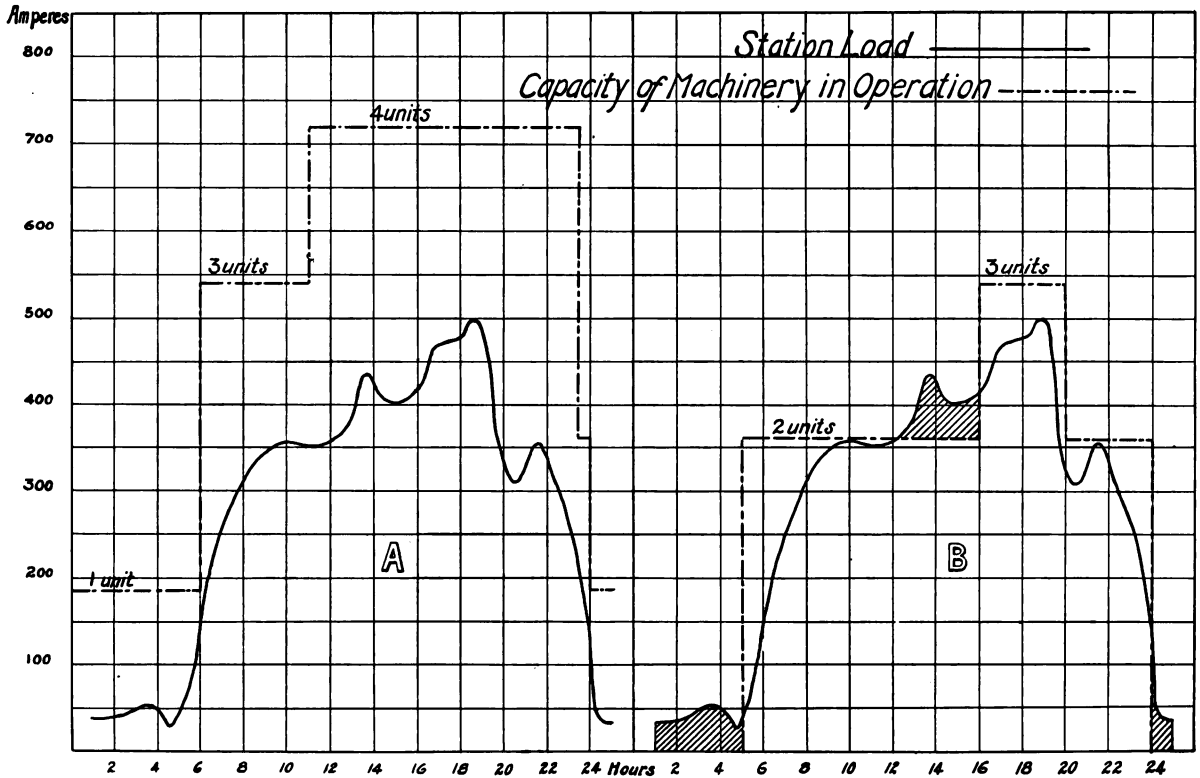


FIG. 4.

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battery as shown by curve B enables the load to be carried on two engines most of the time and three engines maximum, always leaving one engine as a spare besides reducing the hours of engine operation from 64½ to 42 or 35%, a saving in friction load alone of 2250 K. W. hours equal to $13.40 in coal per day. In order to do this the battery must wipe out all fluctuations beyond what the fly wheel can readily take care of, and must also carry the whole load from midnight to 5 a. m., during which time the machinery is entirely shut down, and further it must discharge between 12 A. M. and 4 P. M. when the load exceeds the capacity of machinery in operation. Charging takes place during any of the three periods when the generating capacity in operation exceeds the load.

In small railways driven by water power one of the functions of a battery is to regulate the voltage as well as the load. The difficulty encountered here is in obtaining a governor capable of effecting a change in the water supplied to the wheel with sufficient rapidity to keep step with the fluctuations of a railway load. None of the small railway plants which have come under the observation of the writer have had satisfactory governors and as a result the speed of the wheel is continually varying, rising as the load diminishes and dropping as the load increases. It is not uncommon for the voltage in such plants to vary from 425 to 625 and in bad cases from 375 to 750 even, at the station bus bar. The battery brings an immediate remedy by steadying the load on the wheel which is then called on to govern only for changes in average load.

The opportunity for saving and improvement in the service is quite as great where a battery is used in connection with the distributing system of a railway as it is when installed in the power station. The influence that a line battery will exert in regulating the load of a power station cannot be as great as that of a battery in the station itself, owing to the distance that separates them and the drop in the feeders. The distance, cross section of copper, and number of cars between them will determine this question. On the other hand there is a saving in copper effected by causing the feeders that are installed to be

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used at times when they would otherwise be idle, and this may reach several times the cost of the battery. The battery charges during moments of light load and discharges when the demand in its vicinity is heavier than the average. The energy so discharged is obtained at a much higher voltage than would be the case if it had to come from the power station just at the moment when wanted. By way of illustration let us consider a rather striking case. Suppose a line of railway 12 miles long with a water power station at one end and a long 8% grade at the other end operating two cars on hourly time. The cars take 30 amperes each, average, excepting on the hill where they take 100 amperes. The copper installed is a 0000 trolley and the rail weighs 50 lbs. per yard. The resistance of the circuit is 3.6 ohms, and the average voltage at the grade is 450 supposing the station voltage to be 560; but with a car climbing the grade and taking 100 amperes the pressure drops to 200 volts, too low for satisfactory operation. A battery rated for a maximum discharge of 100 amperes and having 216 cells, or a sufficient number to balance an average voltage of 450, would cost $5,000 installed including the building, and it would furnish the car on the hill with 65 amperes at 430 volts, the remaining 35 amperes coming from the station. The energy discharged by the battery is regained while the car is further back on the line. To furnish the whole 100 amperes from the station and maintain 430 volts at the grade would call for the addition to the line of a 750,000 C. M. feeder at a cost installed of about $22,000.

The reduction in first cost of a transmission system resulting from the use of an accumulator in connection with an intermittent demand is equivalent to the extension of the distance over which direct current feed is possible. The question of holding up the voltage at the end of a long line is sometimes solved by the use of a series booster taking current from the positive bus and feeding at a high pressure through a special feeder to the section needing help. The idea is to substitute wasted energy, or an operating charge, for copper investment. As a general rule, however, where coal is the source of energy

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continuous boosting does not pay. The machine is series wound and in theory varies its voltage with the load so as to compensate as nearly as possible for the volts lost in the boosted feeder at all loads. Owing to the instability of a series generator it is apt to either over or under regulate and supply either more or less than the expected voltage. It also aggravates the already severe fluctuations of a small railway power plant because its load varies with the square of the demand on the line; in other words, doubling the demand quadruples the booster load. Suppose a motor driven booster set having a combined efficiency of 65% engaged in supplying a feeder of 3 ohms resistance with the load running from zero to 150 amperes, but averaging only 50 amperes. The corresponding demand on the power station would run from zero to 103 K. W., averaging only 12 K. W., and the capacity of the set would have to be at least 60 or 70 K. W. Where a battery is operated on the line in connection with a booster the disagreeable features of a series machine may be eliminated and a shunt wound machine substituted for it. The battery takes care of all fluctuations and reduces the load transmitted over the boosted feeder to the average. The shunt wound booster generates a steady voltage and transmits a steady load, and its capacity need be sufficient only for the average. Thus in the case just imagined only 12 K. W. would be required in place of 60 or 70 K. W. There would also be less energy wasted. This arrangement effectually meets a condition which is found on many small roads, where on Sundays and holidays in summer, the load is often more than twice the ordinary. Suppose the transmission system to include a battery, the copper installed will only be sufficient to maintain the average voltage required at the battery under the ordinary conditions of load. On the heavy days when the load doubles, the voltage drops proportionately and the battery must be overworked or else have a corresponding number of cells cut out of circuit. The lowering of the voltage causes the service to suffer considerably. With a booster in the station to supply current to the battery the voltage at that point, generally near the end of the line, and the proper number of cells in the battery may be maintained

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securing good service. By allowing the battery to discharge more than it charges the average voltage may be raised by the amount by which the feeders are lightened. Figure 5 shows the line voltage at a battery substation with and without the battery in service. No booster was in operation in this case, and the raising of the voltage is due to the fact that the battery was discharging considerably more than it received.

Where the distance to be covered exceeds ten or fifteen miles

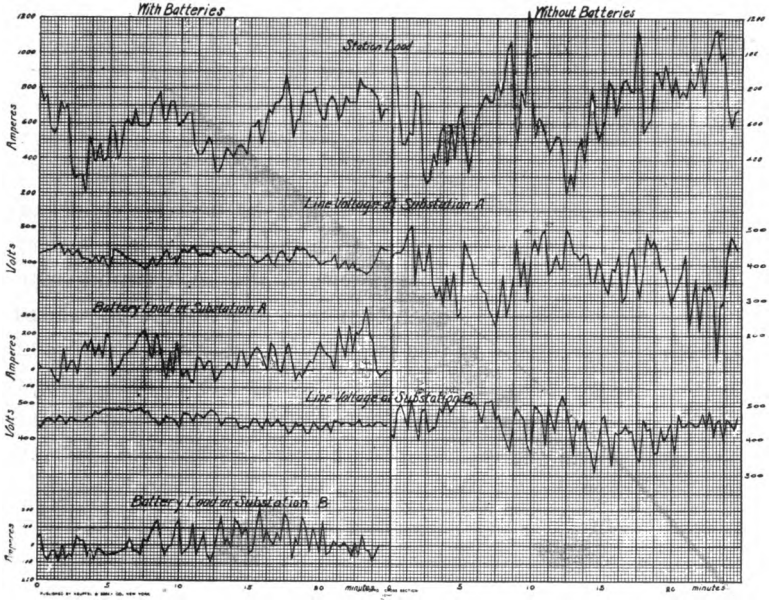


FIG. 5.

from the power station it becomes necessary to make use of alternating current for transmission purposes, but the actual current which drives the car is still direct and the battery is just as useful as if the plant were entirely direct current. In the west the growth of the long distance electric railway has been very rapid, and roads covering distances up to fifty miles are fed from a single central station driven either by steam or water. Alternating current is generated and sent out at pressures run-

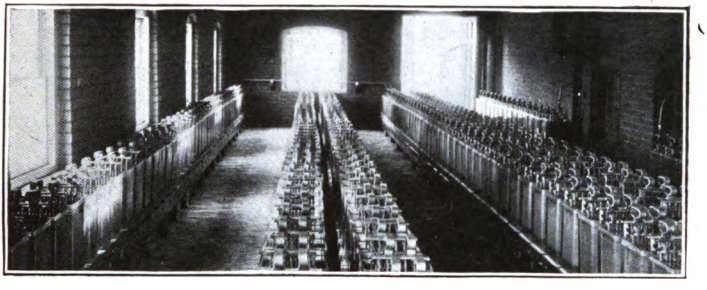
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ning from 5000 to 50,000 volts according to circumstances. Substations are scattered along the road at intervals of ten or fifteen miles and convert the high tension alternating current to direct current at 500 or 600 volts. By providing each rotary substation with a battery, the generating station as well as the distributing apparatus can be designed for the average load, and moreover any accident to the alternating side of the system, putting a rotary out of service, will not block the road, as the battery will usually furnish sufficient reserve to operate its section until the trouble can be removed. Should the rotary go out of step it is readily started again by direct current from the battery, and this is usually the way of starting at all times in such stations, being more satisfactory than starting from the alternating end.

In some of the long distance transmissions like those on the Pacific coast where energy is developed by a water power and transmitted a very long distance to be utilized for all forms of service, lighting, railway and power, it has been found impossible to get satisfactory operation without battery regulation. For although the railway power is furnished by an entirely different set of rotaries from that supplying the lighting system, still the alternating current for both usually comes over the same transmission line and therefore the irregularities and inductive troubles due to the fluctuating railway load react on the lighting system. When used in water power plants as a peak battery to level off the load curve to something near the average, the accumulator may be the means of saving enough money to the owner to cover the interest and depreciation charge on the battery investment and leave a fair profit besides. This fact is particularly evident where the user is buying power from a generating company. The latter must have machinery enough installed to meet the maximum demand of the customer even though his demand may not last more than twenty or thirty minutes. Accordingly the seller usually charges a yearly sum, twenty to thirty dollars per horse power, for the maximum demand needed and the customer is at liberty to use power to that amount twenty-four hours per day if he can. A load averaging 1000

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H. P. and having a peak reaching 1500 H. P. for an hour and a half only, at $25 per H. P., would cost $37,500 per year. A battery to wipe out the 500 H. P. peak might cost $50,000 and the interest and depreciation charge at 10% would be $5,000, but the saving in power would be $12,500, leaving a net profit of $7,500 a year for the owner.



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EDITORIALS.

During the past college year of 1901–02, the Engineering Society has had at six of its regular meetings very interesting and instructive lectures. At the November meeting Mr. W. E. McKay, chief engineer of the Dorchester Station of the Boston Gas Co., read a paper, as published above, on the manufacture of gas and the use of the by-products; at the December meeting, Mr. C. G. Wilson of the Westinghouse, Church, Kerr & Co. read a paper on the Steam Loop and Holly Gravity Return System, which was published in the April issue of this magazine; at the January meeting, Mr J. C. Moses, chief draughtsman of the Boston Bridge Works, gave a talk on the general draughting methods of that company; at the February meeting, Mr. Charles H. Morse, Head Master of the Ringe Manual Training School, lectured on the subject "Practice and Theory for

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the Young Engineer"; at the March meeting Mr. John E. Cheney, assistant engineer of the city of Boston, gave a stereopticon lecture on the West Boston Bridge; and at the May meeting, Mr. E. M. Blake '99 who was assistant engineer of a section of the Rapid Transit Subway in New York City gave a stereopticon lecture on that subject. The October and April meetings were social gatherings.

Besides these regular meetings two special lectures were delivered March 27 and 28 by Mr. Frank W. Skinner, one of the editors of the Engineering Record, on the "Cantilever Method of Bridge Construction" and "Shaft Sinking," which were open to all members of the University.

The Society held its annual dinner at Hotel Westminster May 16, 1902. Owing to the unavoidable absence of Prof. Hollis, Prof. Johnson acted as toastmaster. The dinner was well attended. The invited guests were Mr. W. E. McKay and Mr. J. C. Moses.

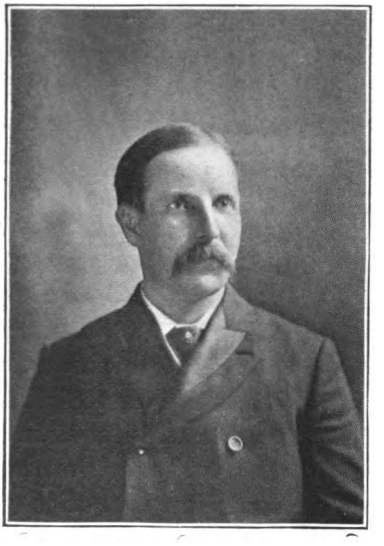
During the past winter an organization calling itself the Topiarian Club, has been formed by the students of landscape architecture to advance their interests and supplement the work of the Pen and Brush Club. The word "Topiarian" was formed from topia which signifies the practice of landscape architecture. The functions of the club are various enough to be in keeping with the breadth of the profession, and include the securing of public lectures on subjects of interest to landscape architects, a sketching class, and excursions varying in character from visits to art galleries to roughing trips on the Cape.

The department of electrical engineering has assumed such proportions that it was deemed necessary to obtain another professor, and accordingly Dr. A. E. Kennelly was elected to serve for five years from September 1, 1902. He will give a full third year course (Eng'g 16c) on direct current dynamo-electric machinery, which replaces a former half course on the same subject. He will also give two fourth year half courses, one (Eng'g 17a) on electric transmission and distribution of power, and the second (Eng'g 17b) on telegraphy and telephony, which are his specialties.

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ARTHUR EDWIN KENNELLY.

Dr. Arthur Edwin Kennelly, the son of a captain in the Royal Navy, was born in Bombay, India, Dec. 17, 1861. At an early age he went to London for his education, and graduated from the University College School. It was during his stay at this school that he became interested in electricity which was then coming into prominence. In 1877, he was made, at the early age of 16, assistant secretary of the Society



A. E. Kennelly.

of Telegraph Engineers. A year later he accepted a clerkship in the employ of the Eastern Telegraph Company which he held for two years at Malta and Porthcurnow.

In 1880, he became assistant electrician on the steamship Great Northern, and two years later chief electrician of the J. Pender. While occupying this position, he brought out the

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of fault resistance which bears his name, and shortly after invented a method of localizing faults in submarine cables. He also propagated, with the assistance of Mr. James Anderson, the famous "earth-over lap" tests.

He was employed by the same company, the Eastern Telegraph Co., on various other steamers. While in the employ of this company, he was awarded a premium for a paper on his new method of localizing faults in submarine cables, by the British Institution of Electrical Engineers, and a year later for another article, the Fahre premium from the same institution.

In 1888, he accepted the position of electrician in the laboratory of Thomas A. Edison at East Orange, N. J., which he held for six years when he joined forces with Prof. Edwin J. Houston as electrical expert and consulting engineer in Philadelphia, Pa. This, by the way, is his present occupation.

He has contributed largely to scientific and engineering literature. He has written articles jointly with Mr. H. D. Wilkinson, and also with Prof. Houston. He has also published two well known books. His articles are particularly marked by their concise perspicacity and fluency. The writer's style is simple and easy in every respect.

Dr. Kennelly has originated several laboratory processes, and designed several electrical instruments. For original research work in electricity, he received from the Western University of Pennsylvania the honorary degree of Doctor of Science.

He is a Fellow of the Royal Astronomical Society, a member of the British Institution of Electrical Engineers, the Franklin Institute, past president of the American Institute of Electrical Engineers, and a member of various other bodies.

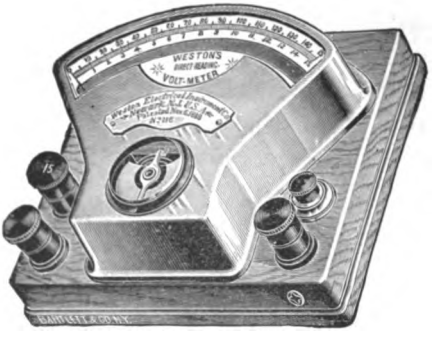
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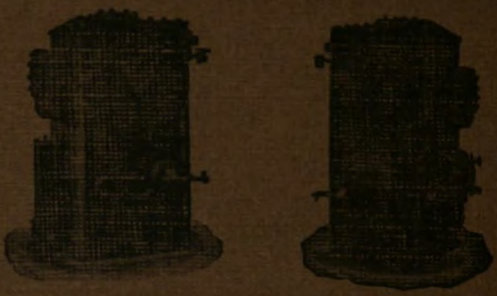
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Given the necessary exhaust steam, the **COCHRANE FEED-WATER HEATER & PURIFIER** will heat water of any temperature to practically the boiling point. The average initial temperature is, say, 60°; difference between 60° and 210° = 150° — a saving of 15% in fuel (1% for each 10°). In a year this saving would pay for the heater several times over — and a few other things beside.

Then the **COCHRANE HEATER** saves water — usually over 14% of the total supply required — by conserving the condensed exhaust steam, which is free from scale forming matter, being distilled water. There are other advantages of the **COCHRANE** described in catalogue 37-H. Write for it.

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HARVARD ENGINEERING JOURNAL



DEVOTED TO THE INTERESTS OF
ENGINEERING AND ARCHITECTURE
AT HARVARD UNIVERSITY

Vol. I

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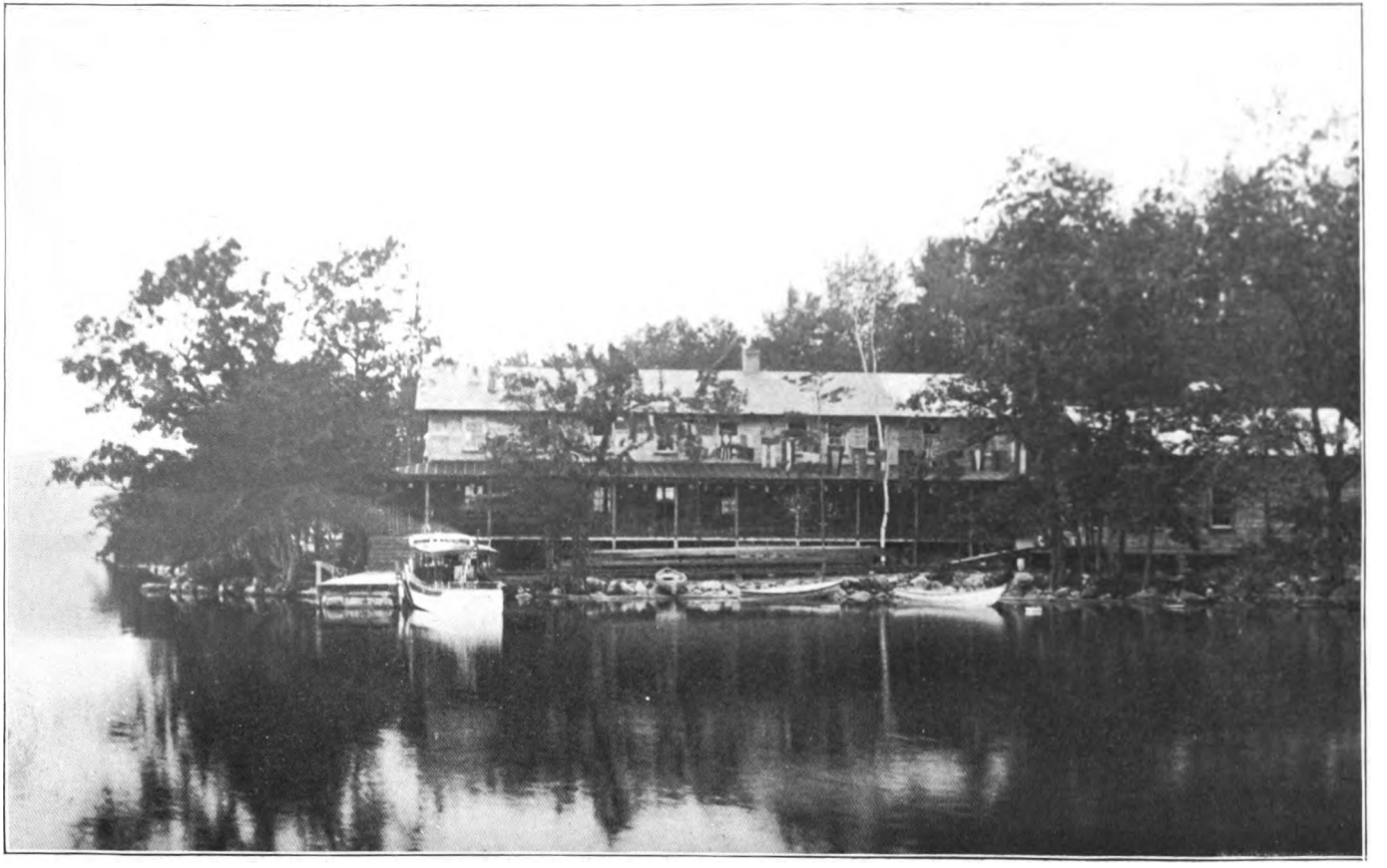
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ENGINEERING JOURNAL

Devoted to the interests of Engineering and Architecture at Harvard University

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VOL. I **NOVEMBER, 1902** **NO. 3**

THE ENGINEERING CAMP AT SQUAM LAKE, NEW HAMPSHIRE.

HENRY HEYWOOD FOX, A. B., 1900.

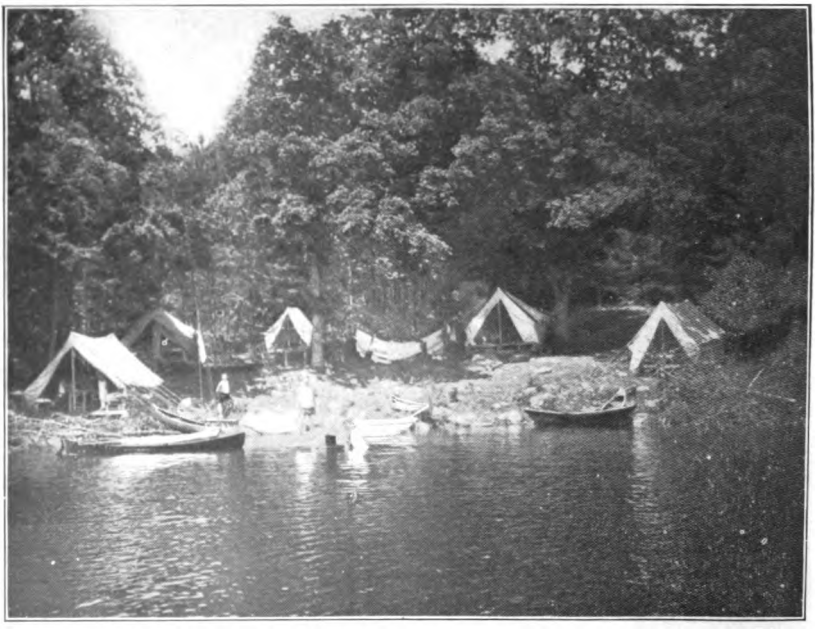
Assistant in Surveying.

THIS year as usual the enrollment at the Camp surpassed all previous records. Since the first years at Martha's Vineyard, when the accommodations consisted of two little old farmhouses and a barn, and the instruments were kept in the instructor's bedroom, the expansion has continued; until now, even with a dormitory big enough for thirty or forty men, twenty-five tents are barely enough to hold the surplus.

The term is longer than it used to be, but the opportunities for relaxation and amusement are correspondingly greater. The life is growing more comfortable. On cold or rainy evenings the living room is a popular center, with its shelves of periodicals, the piano, and a roaring open fire. To be sure, the benches have no backs: one often thinks how acceptable the gift of a few Morris chairs would be. Of course the men do not stay in doors when they can be out. The broad piazza, almost over the water, is a delightful lounging place; and from a canoe the lake is beautiful in the evening. For those who have plenty of energy after four P. M., there is baseball practice and hill-climbing; next summer there will be tennis.

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Considering the program for the working day — breakfast at 6.30, and then work in the field for eight hours — conspicuous energy after four P. M. might be looked upon with suspicion; yet there are men who after really working hard through the



A CORNER OF THE CAMP.

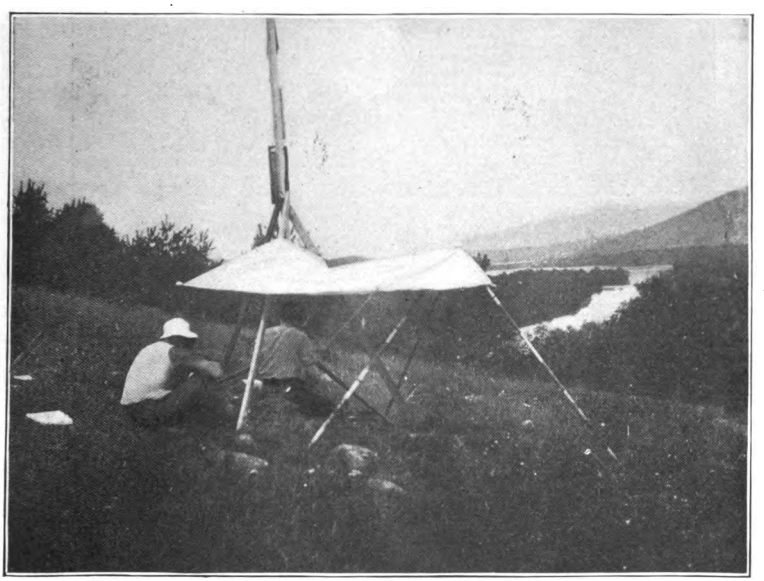
week, use their day and a half of rest to take a twenty or twenty-five mile tramp. The Sandwich range, about fifteen miles to the north, has several peaks, with camps on them, which are attractive objective points.

In the work this summer more tangible results were obtained than ever before. A complete topographical map of the 270 acres of Camp property was made; several railroad lines were located from the Camp to Centre Harbor, four miles away; and the triangulation system was extended to include the whole

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northeastern end of the lake. A great deal else was done, which had value only as practice.

The chief difficulty in the conduct of the course is due to the constant expansion, and the consequent changing conditions. Housing the men is simple: for the tenting ground is unlimited, and most of them prefer the freedom which living in a tent gives, and consider that evenings by a camp fire in good company are the pleasantest hours of the summer. But assigning work for a hundred men is by no means easy, especially since an increase of ten prevents last year's table of assignments from being of any further use. Moreover, as the number of students



TRIANGULATION.

Measuring angles.

increases the number of assistants must increase, and this makes the instruction less uniform. To decrease this difficulty it is probable that a syllabus of the three courses will be published

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before next year. Another puzzling problem occurs in making the triangulation of the lake: namely, how to land fifty men in sections of four at points on the lake a mile or so apart, and get the last section out before it is time to call to bring the first one home.

The instructors look forward to constant conditions; but there seems to be no immediate prospect of them, for so far the number of students has increased regularly, ten per annum.



WORKING ON THE RAILWAY.

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ARMATURE DROP AND REGULATION OF ALTERNATORS.

COMFORT AVERY ADAMS, S. B.

Assistant Professor of Electrical Engineering.

INTRODUCTION.

WHEN the load on an alternator is increased the terminal e. m. f. will in general drop, constant speed and excitation assumed.

This loss of e. m. f. due to the presence of the armature current is called the *armature drop*, and the percentage which the armature drop (under full non-inductive load) is of the terminal e. m. f. under the same conditions, is called the *inherent regulation* of the alternator. Inherent regulation is also defined as the percentage rise of terminal e. m. f. when the full non-inductive load is suddenly thrown off, and is an inverse measure of the ability of the machine to maintain a constant terminal e. m. f. under varying loads but with constant excitation. It is one of the most important characteristics of the alternator.

The predetermination of the armature drop, of the regulation, and of the excitation corresponding to a given load of given power factor, all come under one head and constitute one of the most important problems of alternator design.

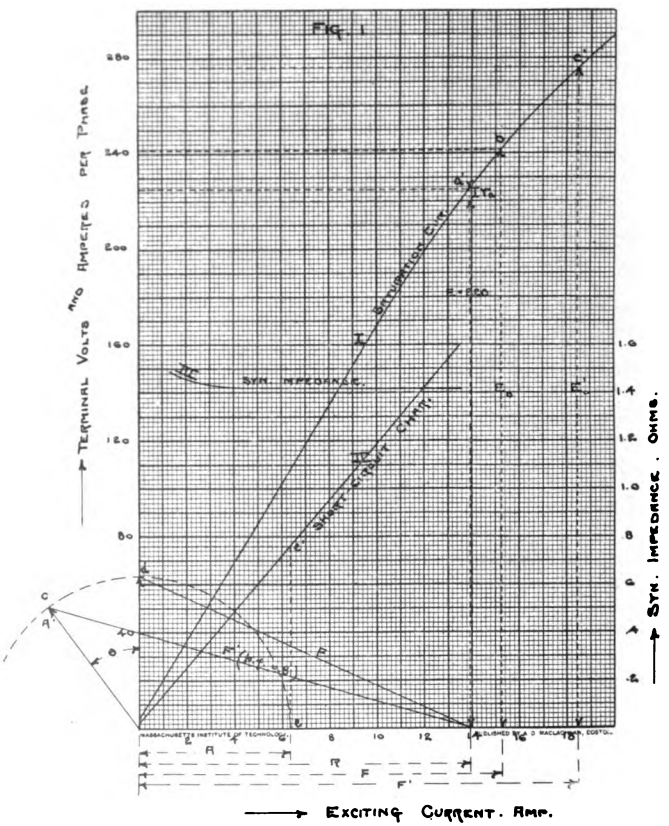
Like many other problems which deal with the magnetic circuit of the dynamo, this one cannot be solved exactly, but is usually solved by a series of compromises and approximations.

When designing an alternator, the problem is a complete predetermination from the dimensions; but even after the machine is built the manufacturer has, in most cases, no direct means of checking the predetermination, since the power to drive one of the large modern direct-connected alternators under full load

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and at its proper speed, can only be supplied by the engine designed for that purpose.

Even after the alternator is installed with its own engine in its final abiding place, there are many difficulties in the way of an accurate test of the regulation. It is therefore very desirable



that there should be some shop method of checking the predetermined value.

The need is partly satisfied by two simple tests requiring very little power, and whose plotted results are known respectively as: the *Saturation Curve*, *Magnetization Curve*, or *Open*

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Circuit Characteristic; and the *Short Circuit Characteristic.* These two are sometimes combined in what is called the *Synchronous Impedance Curve.*

The *saturation* curve is the open circuit e. m. f. at normal constant speed, plotted against the corresponding field current, see figure 1, curve I. Sometimes the useful armature flux replaces the open circuit e. m. f. since the two are proportional.

The calculation of the saturation curve is always a part of the design of every new dynamo, and hence is available before the machine is built.

The *short circuit characteristic* is the short-circuit armature current plotted against the corresponding field current, see fig. 1, curve II.

Synchronous Impedance is the ratio of the open circuit e. m. f. corresponding to a given field current, to the short circuit armature current corresponding to the same field current; i. e., the ratio of corresponding ordinates of the above two curves.

The synchronous impedance curve is the synchronous impedance plotted against field current, see figure 1, curve III. This name is also applied to the curve in which the ordinates of curve I are plotted against the corresponding ordinates of curve II.

The results of these tests, properly applied, eliminate some of the approximations and errors of the complete predetermination and simplify the calculations.

There are several methods of solving the problem in hand, which involve the use of these curves to a greater or lesser degree, and it is the purpose of this paper to describe these methods, to apply them, to point out the field of usefulness of each, and to show its relationship to a general or fundamental method.

There are other less used methods which do not fall directly under the head of the fundamental method referred to, notably those of Blondel[1] and of Parshall and Hobart.[2] Blondel's

[1] Empirical Theory of Alternators, "L' Industrie Electrique," 1899, vol. 8, p. 480, 529 and 555. A. Blondel.

[2] Alternators, London "Engineering," Aug. 3, 24, Oct. 12, 1900.

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method has been recently advocated in a modified form by Mr. L. A. Herdt, in a paper read before the American Institute of Electrical Engineers.

The two factors which play the most important part in the loss of e. m. f. in an alternator armature, are *Armature Reaction* and *Armature Reactance*, and before proceeding with the description of the above mentioned methods, it will be well to consider these factors in some detail.

Armature Inductance and Reactance.

In the magnetic circuit of every dynamo-electric machine there are two m. m. f's., that of the field current and that of the armature current. The resulting flux may in general be divided into three parts: one part linked with both field and armature currents, sometimes called the mutual or useful flux; a second part linked with only the field current, called field leakage; and a third part linked with only the armature current, called armature leakage. It is this armature leakage flux which is represented by the armature inductance. The latter is, in fact, sometimes called the leakage inductance, and the corresponding reactance, leakage reactance.

Armature Inductance is therefore the total linkage of the armature leakage flux with the armature winding, per unit current in that winding.

The armature leakage flux is usually local, that is, in the immediate vicinity of the current producing it, the current in each slot producing a leakage flux which does not get far from the confines of that particular slot and which is linked with only its own current.

Thus a distributed winding with many slots will have a smaller leakage inductance, since the flux generated by each unit of current will be linked with a smaller number of ampere turns.

The Calculation of Leakage Reactance to any considerable degree of accuracy is in most cases impossible, as a little

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consideration will show. It can, however, be very roughly approximated by several methods.[1]

The method[2] given below is largely empirical, very simple, and, when carried not far beyond the limits of one's experience, gives very satisfactory results.

Assume that for every ampere of current flowing through an armature slot there is produced a certain number, ϕ', of flux lines per inch length of slot, linked with the conductors in that slot. The inductance of these conductors can then be easily calculated, thus: assume $\phi'=10$; take a slot 10″ long with 8 conductors; one ampere in each conductor will produce —

8×10 flux lines per inch length,

$8\times10\times10$ flux lines per slot, and

$8\times8\times10\times10$ flux linkages per slot, since the flux is linked with 8 wires. The inductance per slot is then —

$8\times8\times10\times10\times10^{-8}=.000064$ henries.

If the wires of one phase fill 12 slots, the inductance per phase is .00077 henries, and the reactance at 60 cycles is

$2\pi\times60\times.00077=.29$ ohms.

The end connections could be taken account of in a similar manner, but the number of flux lines per ampere per inch would be less. It is simpler, however, where the percentage of end connections is not abnormal, to allow for the same by adding a little to the constant used for the wire imbedded in the slots.

The following considerations affect the accuracy of this method.

All mutual inductance between slots has been neglected, but the error involved is very small.

The constant proportionality between current and leakage flux assumes constant reluctance of leakage path, which is approximately true, since most of that reluctance is in the slot

[1] "Elektrotechnische Zeitschrift," Vol. 21, 1900, p. 549 Niethammer. Also "Ankerwicklungen und Ankerkonstruktionen," page 188, E. Arnold.

[2] Alternators, London "Engineering," Aug. 3, 1900, p. 144, Parshall and Hobart; "Electric Generators," page 160, by the same authors; London "Electrical Engineer," Vol. 28, 1901, pages 481, 519.

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rather than in the iron. The reluctance of the iron part of the path however does count and must be reckoned with at extreme tooth densities, a slightly smaller value of ϕ' being taken.

The reluctance also varies with the shape of the slot, and ϕ' must be chosen accordingly. A broad shallow slot has a relatively large leakage reluctance, and ϕ' is proportionally small; the reverse is true of the narrow deep slot.

The method assumes that all the flux generated by the current in any slot is linked with all the conductors of that slot, which is obviously not the case. There is, however, always an equivalent average value of ϕ'.

The range of ϕ' is from 5 to 15 lines per ampere per inch length of slot; 5 to 10 corresponds more nearly to the modern type with open slots and distributed winding. A little experience with any particular type of machine will enable ϕ' to be very fairly approximated for a new machine of that type.

In modern close regulation machines, however, a considerable error in ϕ' makes a much smaller percentage of error in the result, owing to the relatively small part played by the leakage reactance in this type of machine.

Armature Reaction.

Consider a two pole machine with a single loop of wire on the

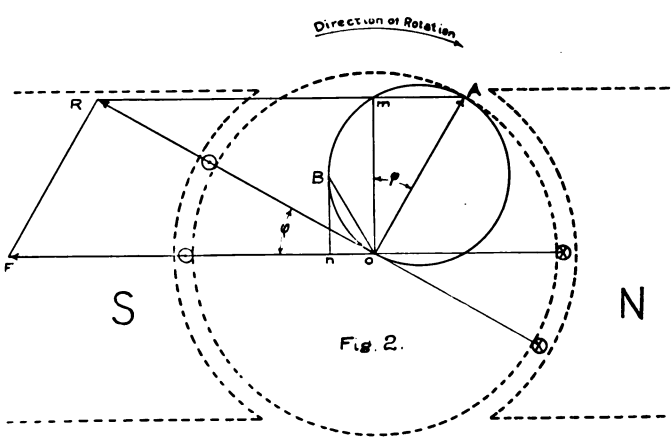


Fig. 2.

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armature, figure 2; the field is excited, and the armature revolving clockwise. Assume a symmetrical flux distribution, a sinusoidal e. m. f. and current.

If the armature circuit be open there will be no current, and the maximum e. m. f. will occur when the plane of the armature coil is horizontal in the figure. If the polarity of the field be as indicated, the induced e. m. f. will be backward ($\oplus$) through the paper on the right and outward ($\odot$) from the paper on the left of the armature.

If now the armature circuit be closed through a non-inductive resistance, a current will flow which is in phase with the induced e. m. f., except for the influence of the armature leakage reactance, which influence may be assumed small. But the armature current will now drag the flux around in the direction of rotation, and the general direction of the resultant field will no longer be horizontal in the figure, but diagonally upwards as indicated by the line $\overline{OR}$.

The maximum e. m. f. and current will now occur when the plane of the coil is in the direction of $\overline{OR}$, i. e., when the wires of the coil are cutting through the strongest part of the field.

The m. m. f. of the armature in this position of maximum current will be perpendicular to the plane of the coil (i. e. to $\overline{OR}$), and may be represented in direction and magnitude by $\overline{OA}$ The m. m. f. of the field will be horizontal and may be represented by the line $\overline{OF}$. The vector addition of these two m. m f's. gives the resultant m. m. f. $\overline{OR}$, to which $\overline{OA}$ must be perpendicular. I. e., $\overline{OA}$ and $\overline{OF}$ being given, $\overline{OA}$ must have such a direction that it will be perpendicular to $\overline{OR}$, the resultant of $\overline{OA}$ and $\overline{OF}$.

But this diagram applies only to the instant of maximum current, whereas, it is evident that as the armature revolves the direction as well as the magnitude of its m. m. f. changes, and if we still assume the current sinusoidal, the armature m. m. f.

[1] Note. In the two pole machine represented in the diagram, one complete cycle (360 electrical degrees) corresponds to a complete revolution (360 mechanical degrees). For a multipolar machine, the diagram would be the same, the complete circle corresponding to only one pair of poles, or 360 electrical degrees.

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corresponding to any position of the armature may be represented by a line perpendicular to the plane of the coil, and drawn from O to the circumference of the circle $\overline{OA}$. E. g., when the coil is horizontal, in line with $\overline{OF}$, the armature m. m. f. will be represented by the line $\overline{Om}$.

It is thus apparent that the armature m. m. f. of a single-phase alternator goes through a cycle of changes both as to its magnitude and direction; and that the resultant m. m. f. and flux will seesaw back and forth about a mean position, changing both in magnitude and in direction by an amount depending upon the magnitude of the armature current.

A common method of analyzing armature reaction is to divide the armature m. m. f. into two components, one in the direction OF of the field m. m. f., and the other at right angles thereto; the former is called the *magnetizing* or *demagnetizing component* according as it is in the same direction as, or in opposition to, the field m. m. f., and the latter is called the *cross-magnetizing component*. E. g., $\overline{Om}$ is the cross-magnetizing component and $\overline{mA}$ the demagnetizing component of $\overline{OA}$; $\overline{nB}$ the cross-magnetizing and $\overline{On}$ the magnetizing component of $\overline{OB}$.

The average armature m. m. f. throughout a complete cycle is in the direction $\overline{OA}$ and therefore has a demagnetizing component proportional to sin ϕ; i. e., although there is a short period during each cycle when the armature m. m. f. is aiding the field, it is, on the whole, demagnetizing. The average demagnetizing effect of the armature current is thus proportional to the strength of that current and to sin ϕ. But sin ϕ itself is proportional to the armature current, assuming $\overline{OF}$ to be constant, for sin $\phi = \frac{\overline{OA}}{\overline{OF}}$, and the demagnetizing effect is therefore proportional to $\overline{OA}^2$, that is, to the square of the armature current.

This may be explained in another way: an increase of armature current results in a double increase in demagnetizing effect because the increased distortion of the field places the armature current in a stronger demagnetizing position, and we thus have an increased proportion of an increased m. m. f.

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The principal effect of the *cross-magnetizing component* of the armature m. m. f. is to produce distortion of the magnetic field; but this distortion and crowding of the flux in the trailing pole corners, increases the reluctance of that part of the magnetic circuit and thus decreases the flux. This is equivalent to an additional demagnetizing effect, though usually of relatively slight importance. On the other hand, if there is any considerable saturation of the trailing pole corners, it will tend to resist the distortion, to throw $\overline{OR}$ and $\overline{OA}$ backwards, to the left, and thus reduce the demagnetizing component of $\overline{OA}$. This at least partly neutralizes the opposite effect above noted.

Effect of lagging current upon armature reaction. If the load on the alternator be inductive, the current will lag and its maximum value will no longer occur with the maximum e. m. f., when the coil is cutting through the strongest field, but at a later period.

The diameter $\overline{OA}$ of the armature m. m. f. circle, will then be shifted farther around in the direction of rotation and $\overline{OR}$ will

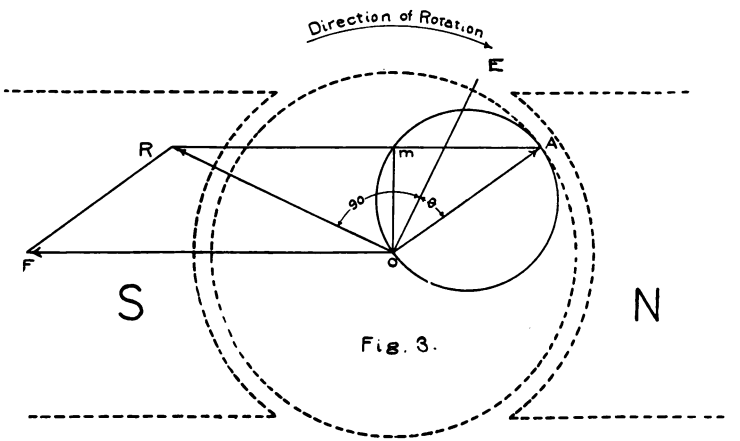


Fig. 3.

also change. If θ is the angle by which the current lags behind the e. m. f., the axis of the armature coil will be θ electrical degrees farther along at the instant of maximum current than at the instant of maximum e. m. f., and since at the latter instant the

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axis must still be perpendicular to $\overline{OR}$, $\overline{OA}$ must be $(90 + \theta)$ electrical degrees in advance of $\overline{OR}$, the latter still being the resultant of $\overline{OF}$ and $\overline{OA}$; see figure 3, where $\overline{OE}$ is the position of the axis of the armature coil when the e. m. f. has its maximum value.

From this it is evident that the lag of the current has increased the demagnetizing component of the armature m. m. f., or, during the lag interval the armature has moved around into a position more favorable for demagnetizing.

On the other hand, a leading current would cause $\overline{OA}$ to be shifted backwards to the left of $\overline{OE}$, which would decrease the demagnetizing component and might even give a resultant magnetizing effect, as in figure 4, where θ is the angle of lead.

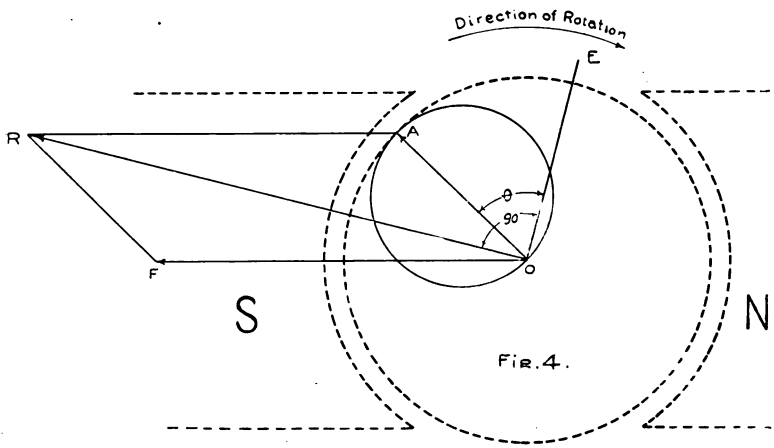


Fig. 4.

In any case, the quantitative relation of the several m. m. f.'s is,

$$F = \sqrt{R^2 + A^2 + 2AR \sin \theta} \qquad (1)$$

or,

$$R = \sqrt{F^2 - A^2 \cos^2 \theta} - A \sin \theta \qquad (2)$$

where F, R and A represent $\overline{OF}$ $\overline{OR}$ and $\overline{OA}$ respectively, and where θ is the angle of lag. In case of a leading current θ is negative.

In applying (1) and (2) to single phase alternators, A should evidently be taken as the average armature m. m. f., not the

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maximum as represented in the diagrams. If the direction be taken into account when averaging, the result will be equal to $\overline{OA} \div 2$, where $\overline{OA}$ is the maximum armature m. m. f. In a single phase multipolar alternator the average ampere turns *per pair of poles* will then be approximately

$$A_1 = \frac{\sqrt{2}\, N_a\, I_a}{4\, p'} = .707\, \frac{N_a\, I_a}{2\, p'} \qquad (3)$$

where N_a is the total number of face conductors,

I_a the r. m. s. current per conductor and

p' the number of pairs of poles.

The value of F corresponding to A_1, will then be the number of ampere turns on two poles, that is, on a complete magnetic circuit.

If the numerical average of the armature m. m. f. be taken, disregarding direction, it will be .64 × $\overline{OA}$ and equation (3) becomes

$$A_1 = .91\, \frac{N_a\, I_a}{2\, p'} \qquad (4)$$

For a much distributed winding eq. (3) gives the best results, and for a unicoil winding eq. (4) is more appropriate.

Armature Reaction in Polyphase Alternators.

Consider a two phase alternator with two coils, 1 and 2, 90° apart, figure 5, which is the same as figure 3, except that we now have two phases. The load is assumed the same on each phase, θ being the angle of lag in each; the maximum current will be the same in the two phases and will occur at the same position, $\overline{OA}$, but at intervals one quarter of a period apart; each current will supply the same cycle of m. m. f's., represented by the circle $\overline{OA}$, but 90° apart. E. g., in the position shown the axis of the two coils, 1 and 2, will intersect the circle OA in m and n respectively, and the two m. m. f's. will be represented in length and magnitude by $\overline{om}$ and $\overline{on}$. But it is evident that the vector sum of these two m. m. f's. is equal to $\overline{OA}$, and that this will be true for every position of the coils, so long as they keep the same relative position.

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In other words, the resultant armature m. m. f. is fixed in direction and magnitude, for any given load, and what was true of only the maximum value of the single phase armature m. m. f. holds at each instant for the resultant two phase m. m. f.

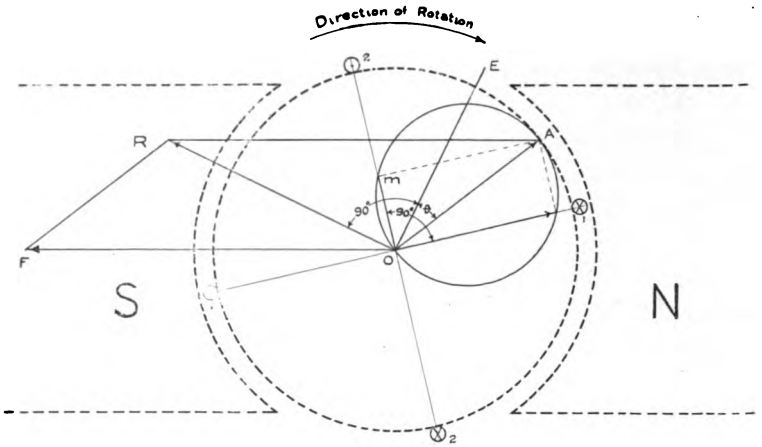


Fig. 5.

The same can be shown to be true of a symmetrical three phase armature, figure 6. The axes of the coils 1, 2, and 3, intersect the circle $\overline{OA}$ at m, n, and p respectively. It is a simple exercise in trigonometry to show that the resultant of the three m. m. f's., $\overline{om}$, $\overline{on}$, and $\overline{op}$, lies in the direction $\overline{OA}$, and is in magnitude equal to $\frac{3}{2}\overline{OA} = \overline{OA_3}$, no matter what the position of the armature.

In a similar manner it could be shown that the resultant m. m. f. of any symmetrical balanced polyphase armature is fixed in magnitude, and in direction with respect to the field structure. If the machine in question is of the revolving armature type, the resultant armature m. m. f. is stationary in space, and revolves backwards relatively to the armature with a velocity equal to that with which the armature revolves forwards.

In this case, what may be called the *armature current distribution* is also stationary; i. e., those wires which are under the

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north pole always carry a current in one direction, and those under the south pole, in the opposite direction, the total ampere conductors on one side of the armature remaining approximately constant, whereas in the single phase alternator the number of ampere conductors varies from zero to a maximum value.

The current as distinguished by its direction may thus be said to be stationary, and the conditions are much the same as in the case of the direct current generator.

In the case of the revolving-field type of alternator the resultant armature m. m. f. and the current distribution revolve with the field structure and at the same speed.

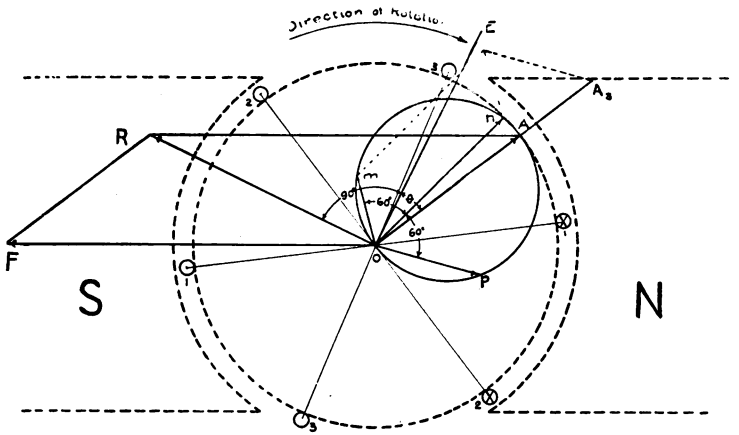


Fig. 6.

We have seen above that for a two phase armature A is equal to the maximum value of the m. m. f. of one of the phases, and, in the three phase case, to 1.5 times the maximum m. m. f. of one phase. Thus when measured in ampere turns, A becomes for the two phase armature,

$$A_2 = \frac{2\sqrt{2}\,N_a I_a}{8\,p'} = \frac{\sqrt{2}\,N_a I_a}{4\,p'} = .707\,\frac{N_a I_a}{2\,p'} \qquad (5)$$

and for the three phase armature,

$$A_3 = \frac{3\sqrt{2}\,N_a I_a}{12\,p'} = \frac{\sqrt{2}\,N_a I_a}{4\,p'} = .707\,\frac{N_a I_a}{2\,p'} \qquad (6)$$

In applying equations (3), (4), (5), and (6), the following points should be kept in mind.

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Equations (3) and (4) for the single phase case are the results of different methods of averaging a quantity which varies both in direction and magnitude, and the question as to which, if either, is reasonably near to the true effective average, depends upon the degree of distribution of the winding and the shape of the poles, a unicoil winding giving a larger value of A than a multicoil winding. The degree of distribution affects also the values of A_2 and A_3 in the same direction, although to a lesser extent.

All of these quantities are affected by the wave form of the current, a flat topped wave giving larger values than a peaked wave. The above values are based on the sine wave assumption.

If the pitch of the coils is less than 180°, (electrical), the resultant armature m. m. f. will be less than that given by the above equations. This is very marked in three phase alternators with fractional pitch windings.

The compounding of m. m. f's. as above, implies a symmetry and homogeneity of the magnetic medium which does not exist, since the polar projections and interloper spaces of the ordinary alternator influence the field distortion to a considerable degree.

A more exact analysis is, however, so laborious that the simple composition of m. m. f's. is usually employed.

It is also to be noted that F, which we have taken above as the total field m. m. f., should strictly be only that part of the field m. m. f. which combines with the armature m. m. f., A, to make the resultant m. m. f., R; since the remainder of the field m. m. f. is consumed in overcoming the reluctance of the field cores and yoke, where the flux is not distorted by the armature reaction.

If then F be taken in the above diagrams as the total field m. m. f., the resulting distortion and corresponding demagnetizing component of the armature m. m. f. will be less than the actual. There is, however, another influence which partly balances this discrepancy, namely, the saturation of the trailing pole corners, which resists the distortion and thus tends to reduce the demagnetizing component of the armature reaction.

On this account and because of the difficulty of a more careful analysis, F will be taken as the total field m. m. f.

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The effect of the above factors upon the armature drop will now be represented by means of a vector diagram.

General Alternator Diagram.

Let the line $\overline{O\Phi}$, (figure 7), represent, both in direction and magnitude, the resultant or mutual flux, Φ.

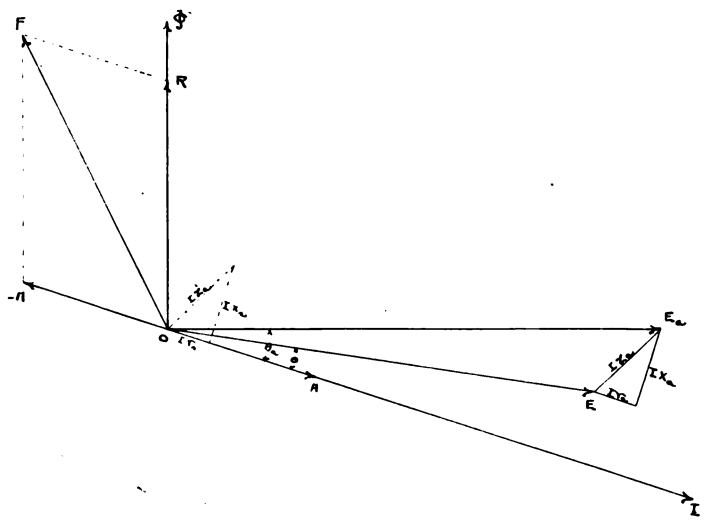


Fig. 7.
General Alternator Diagram.

The m. m. f., R, which produces this flux will have the same direction and may be represented by the line $\overline{OR}$, which corresponds exactly to the line $\overline{OR}$ of the preceding figures.

The cutting of the flux Φ will result in an e. m. f., E_a, represented by $\overline{OE}_a$ in the diagram.

The direction of this line has a double significance: with clockwise rotation of the armature, it is, as in preceding figures, the direction of the axis of the armature coil at the instant of maximum e. m. f., it also represents the phase of E_a with respect to Φ. From this latter standpoint the diagram is an ordinary

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time vector diagram, in which the vectors are supposed to revolve counter-clockwise about O and to represent by their vertical projections at each instant the corresponding instantaneous values of the respective variables.

From this point of view Φ is a variable so far as the armature coil is concerned, although it is fixed in space-direction and magnitude.

With a given total armature e. m. f., E_a the armature current will depend upon the armature resistance, r_a, the armature leakage reactance, x_a, the load resistance, r, and load reactance, x. In magnitude it will be: —

$$I = \frac{E_a}{\sqrt{(r_a + r)^2 + (x_a + x)^2}}$$

and will lag behind E by an angle θ such that $\tan \theta = \frac{x_a + x}{r_a + r}$

This is represented in the diagram by the line $\overline{OI}$, which has the same double interpretation as had $\overline{OE_a}$, showing not only the relative time-phase and magnitude of I but also the direction of the axis of the armature coil at the instant of maximum current.

Of the total induced e. m. f., E_a, a portion, Ir_a, in phase with I, is consumed by armature resistance; another portion, Ix_a, 90° ahead of I, is consumed by armature reactance; and the remainder, E, is available at the terminals of the armature.

We have seen in previous diagrams that the average armature m. m. f. in the case of a single-phase, and the constant m. m. f. in the case of a balanced polyphase armature, are in the direction of the axis of an armature coil at the instant of maximum current in that coil, therefore in the direction $\overline{OI}$ in figure 7. This is the space aspect of the diagram, rather than the time aspect.

Let $\overline{OA}$ represent this armature m. m. f., or ampere turns, to the same scale as that used for $\overline{OR}$; then the field m. m. f., F, must be such that R is the resultant or vector sum of F and A; or, F must supply the component R, consumed by the reluctance of the magnetic circuit, and another component, $-A$, to balance or neutralize the m. m. f., A, of the armature.

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The diagram of figure 7 thus represents both time and space relations, and is very helpful in the solution of many important problems in connection with alternators.

It is here called the *general* alternator diagram, since it is the one of which the others are modifications or special cases; it is also more fundamental than the others, since it represents, as nearly as is possible, real quantities, whereas the modifications to be described below, introduce hypothetical quantities as substitutes for some of the real quantities. These substitutes are sometimes fairly equivalent, but involve additional approximations and errors, which are sometimes of considerable magnitude.

There are two factors not considered in this diagram which contribute in lesser degree to the armature drop.

These factors are: the demagnetizing action of the eddy currents which are induced by the armature leakage flux; and the increase of reluctance of the field cores and yoke due to the increased field leakage which accompanies an increase of load.

The demagnetizing effect of the eddy currents cannot be calculated with any useful degree of accuracy, but may be fairly approximated from experience.

Since the eddy current loss is energy expended by the armature current it will have much the same effect as an increase of armature resistance and may be so represented. This increased armature resistance, sometimes called the *equivalent resistance*, varies from 1.2 to 1.5 times the ohmic resistance. Thus no change in the diagram is necessary, except the substitution of this equivalent resistance for r_a.

The increased reluctance due to increased field leakage is appreciable only when the field cores or yoke are near saturation. The method of determining the effect of this increase is as follows: In figure 8, Curve F_o is the saturation curve of the machine in question; curve $\underline{Ni}_{f+y}$ is the m. m. f. consumed in the field cores and yolk; assume that F at full load $= 1.4 \times F$ at no load, or $F_f = 1.4\ F_o$, as determined from the general diagram, see below; assume the field leakage coefficient at no load to be $\nu_o = 1.3$; then at full load the leakage will be increased

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by 40%, since it is proportional to F, and the full load leakage coefficient will be $V_f = 1 + .3 \times 1.4 = 1.42$, i. e. the field flux has increased from 1.3 to 1.42, or 9.2%; the increased m. m. f. necessary will depend upon the shape of the curve $\underline{Ni}_{f+y}$; this increase is designated $\underline{Ni}_1$ in figure (8). The case chosen is somewhat extreme, but it shows well the possible importance of this factor; and although in most cases it amounts to little, it may not safely be neglected in all cases.

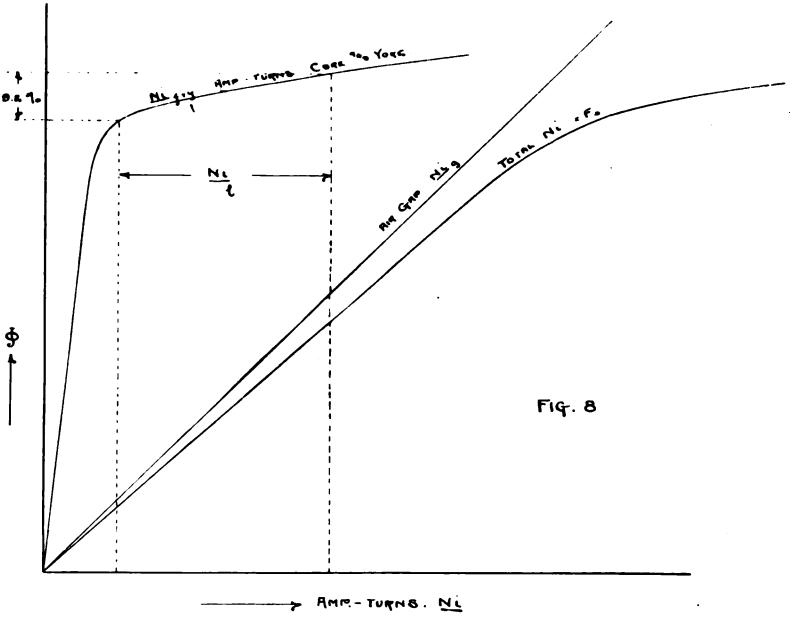


Fig. 8

In machines with fields highly saturated for purposes of regulation, this increase of reluctance may make it impossible to maintain normal voltage under full load, without overheating the field.

Application of General Alternator Diagram.

To calculate the excitation, F, necessary to produce a desired terminal voltage, E, and current, I, at a given power, cos θ, Fig. 7.

Lay off E and I in their given phase relation; add vectorially

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to E the armature impedance drop Iz_a, to get E_a; calculate the corresponding Φ from the ordinary e. m. f. equation; look up on the saturation curve (calculated or observed), the ampere turns R necessary to drive the flux Φ through the reluctance of the magnetic circuit; calculate A by means of equations (3), (4), (5) or (6); finally compound R and $-A$ as above, to get F, the desired field ampere turns.

Inherent Regulation. If the above load for which F was calculated, be taken as the full non-inductive load, the no load voltage, E_o, for the same F can be taken directly from the saturation curve, and the inherent regulation, $\frac{E_o - E}{E}$, can thus be determined.

If x_a be calculated (see page 149), and the saturation curve be calculated, the above method will be a complete predetermination. After the machine is built, however, the saturation curve can be easily taken in the shop and x_a be measured by methods to be described below; or since the measurement of x_a is somewhat indirect and less accurate than the saturation curve, the calculated value may still be used, especially if the machine is of a familiar type, where ϕ' can be closely approximated.

In applying this method, the diagram may be drawn to scale and the unknown quantities actually measured therefrom; or if greater accuracy is desired, algebraic expressions for the various relations involved can be easily developed from figure (7); thus:

$$E_a = \sqrt{(E \cos\theta + I r_a)^2 + (E \sin\theta + I x_a)^2}$$

$$\tan\theta_a = \frac{E \sin\theta + I x_a}{E \cos\theta + I r_a}$$

$$\sin\theta_a = \frac{E \sin\theta + I x_a}{E_a}$$

$$\cos\theta_a = \frac{E \cos\theta + I r_a}{E_a}$$

$$F = \sqrt{(R + A \sin\theta_a)^2 + A^2 \cos^2\theta_a}$$

The chief function of the vector diagram is to present to the mind's eye in abbreviated form, a problem otherwise complicated. For numerical solution the algebraic method is much to be preferred. There are cases however, such as the present one, in

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which the errors of the graphical method are so small as compared with other errors inherent in the problem that this method is amply accurate.

Two examples of the general method follow, in which the saturation curves were observed, and x_a calculated by assuming $\phi' = 10$.

Examples.

Example # 1. *50 K. W. 3* Phase Alternator.

Revolving field; 60 cycles; 6 poles; 1200 r. p. m.; 220 volts; delta connected; 76 amperes per phase; 131 amperes line current; 36 slots; 12 slots per phase; 8 conductors per slot; length of armature core = 8″; imbedded length of conductors = 6.5″; field turns per pole = 230, per pair of poles = 460; ohmic armature resistance per phase = .045 hot; equivalent armature resistance per phase = .065 (assumed); assume 10 lines per ampere per inch imbedded length;

flux per slot per ampere = $10 \times 8 \times 6.5$

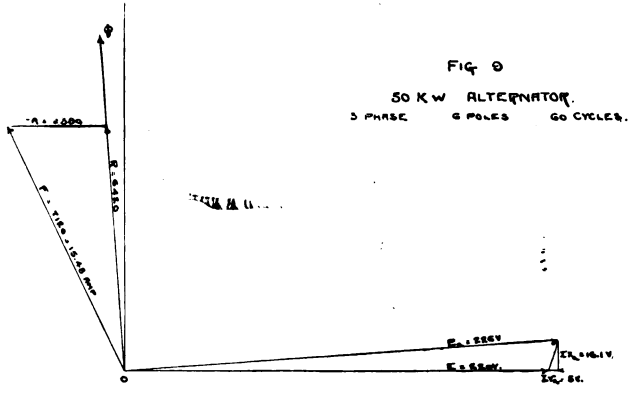
flux linkage per slot = $10 \times 8 \times 6.5 \times 8 = 4160.$

flux linkage per phase = $4160 \times 12 = 56000.$

inductance per phase = .00056 henries

x_a = reactance per phase = $.00056 \times 2\pi \times 60 =$.212 ohms.

The observed saturation curve is given in figure 1, curve I. *Excitation for full non-inductive load.* See figure 9.



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$E = 220$, $Ir_a = 76 \times .065 = 5$ volts; $Ix_a = 16.1$ volts;

$E_a \sqrt{225^2 + 16.1^2} = 226$ volts;

the corresponding field current taken from the saturation curve is 13.9 amperes which is equivalent to $13.9 \times 460 = 6400$ ampere turns per pair of poles, i. e., $R = 6400$; lay off R perpendicular to E_a; $A = .707 \frac{N_a I_a}{2 p'} = .707 \times 48 \times 76 = 2580$ ampere turns; I and A are in phase with E, and $-A$ in opposition thereto; add $-A$ to R geometrically, to get $F = 7120$ ampere turns $= \frac{7120}{460} = 15.48$ amperes of field current. The observed value was 15.1+ amperes.

Regulation. The open circuit voltage corresponding to this field current is, from the saturation curve, 241.5 volts and the Inherent Regulation is $\frac{241.5 - 220}{220} = \frac{21.5}{223} = 9.8\%$.

Example # 2. 1500 K. W. 3 PHASE ALTERNATOR.

Revolving field; 60 cycles; 60 poles; 120 r. p. m.; 2 slots per pole per phase; 4 conductors per slot; 2380 volts; delta connected; armature current per phase = 227 amperes; length of armature core = 16″; imbedded length of conductors = 13″; ohmic resistance per phase = .073 ohms; equivalent resistance (assumed) = .1 ohm per phase; x_a, calculated as in example # 1, assuming 10 lines per ampere per inch of imbedded length, = .94 ohms per phase; turns per pole of field = 51; turns per pair of poles = 102. $A = .707 \times \frac{N_a I_a}{2 p'} = 3850$ ampere turns per pair of poles for full load armature current.

Excitation for full non-inductive load. See figure 10.

$I r_a = 22.7$ volts; $I x_a = 213$ volts;

$E_a = \sqrt{2403^2 + 213^2} = 2412$

from the saturation curve, figure 11, the corresponding field current is 141.3 amperes and $R = 141.3 \times 102 = 14410$.

Add $-A$ to R geometrically and get $F = 15250$ ampere-turns, or 149.5 amperes. The observed value was 150 amperes.

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Regulation. From the saturation curve the open circuit e. m. f. corresponding to 149.5 amperes field current is 2473 volts, and the regulation is $\frac{2473 - 2380}{2380} = 3.9\ \%$.

These two machines are of the same type, by the same maker,

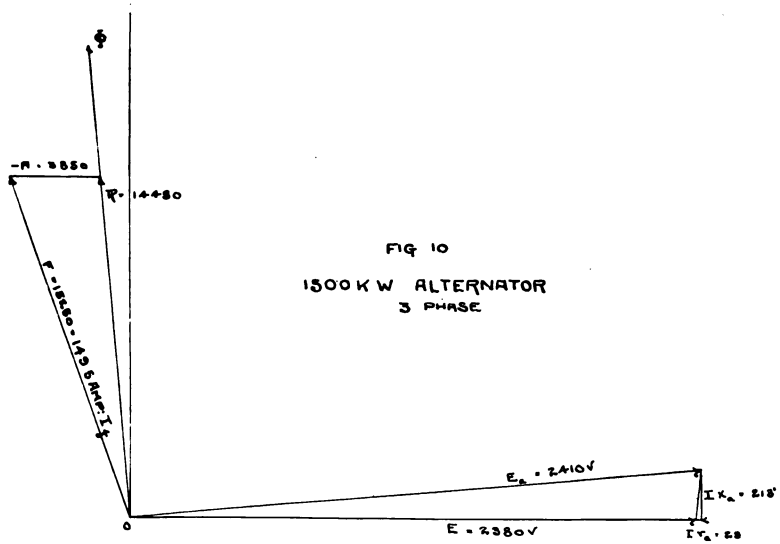


FIG 10

1500 K W ALTERNATOR
3 PHASE

straight sided open slots of about the same width, those of larger machines being somewhat deeper.

The agreement between the calculated and observed results is unusually good in the case of the larger machine, better in fact than is warranted by the accuracy of the data. The agreement in example # 1 is also good, but could have been improved by choosing a somewhat smaller value of ϕ'. The reason for this smaller value is probably higher leakage reluctance due to the shallower slots.

Many other calculations made on this same basis have given excellent results.

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In the above two examples no account has been taken of the increased reluctance due to increased field leakage, because the effect of that increase is very small.

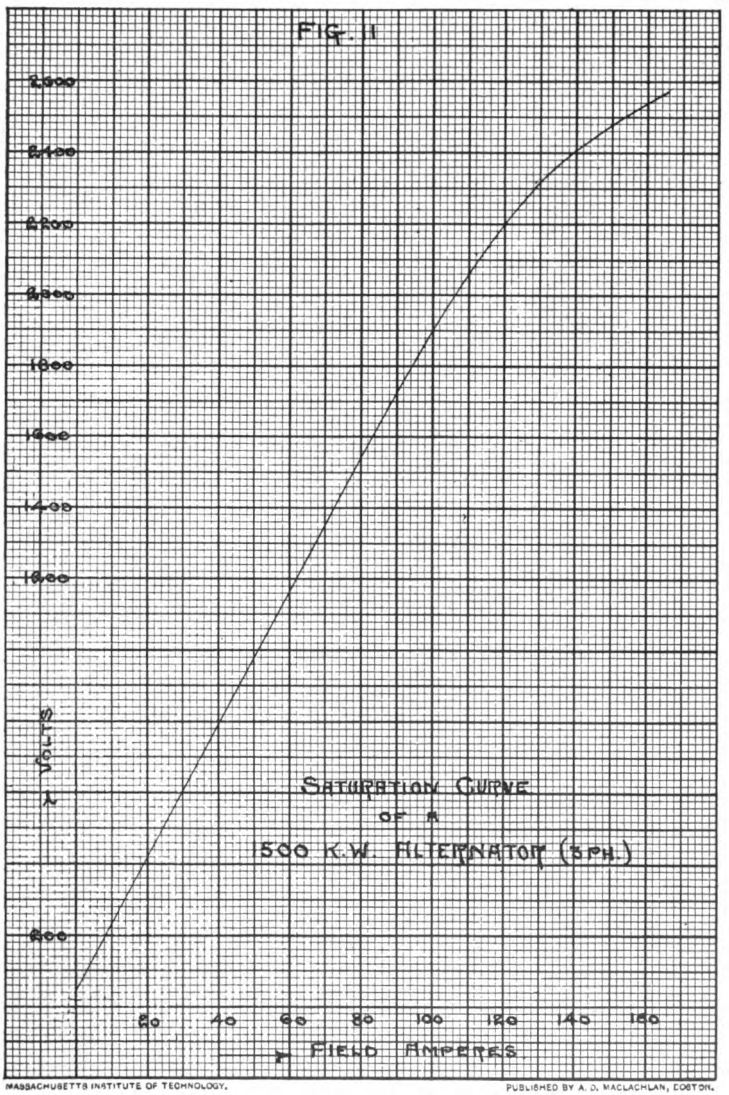


FIG. II.

(*To be concluded.*)

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THE CAMBRIDGE BRIDGE.

JOHN EUGENE CHENEY, '67.

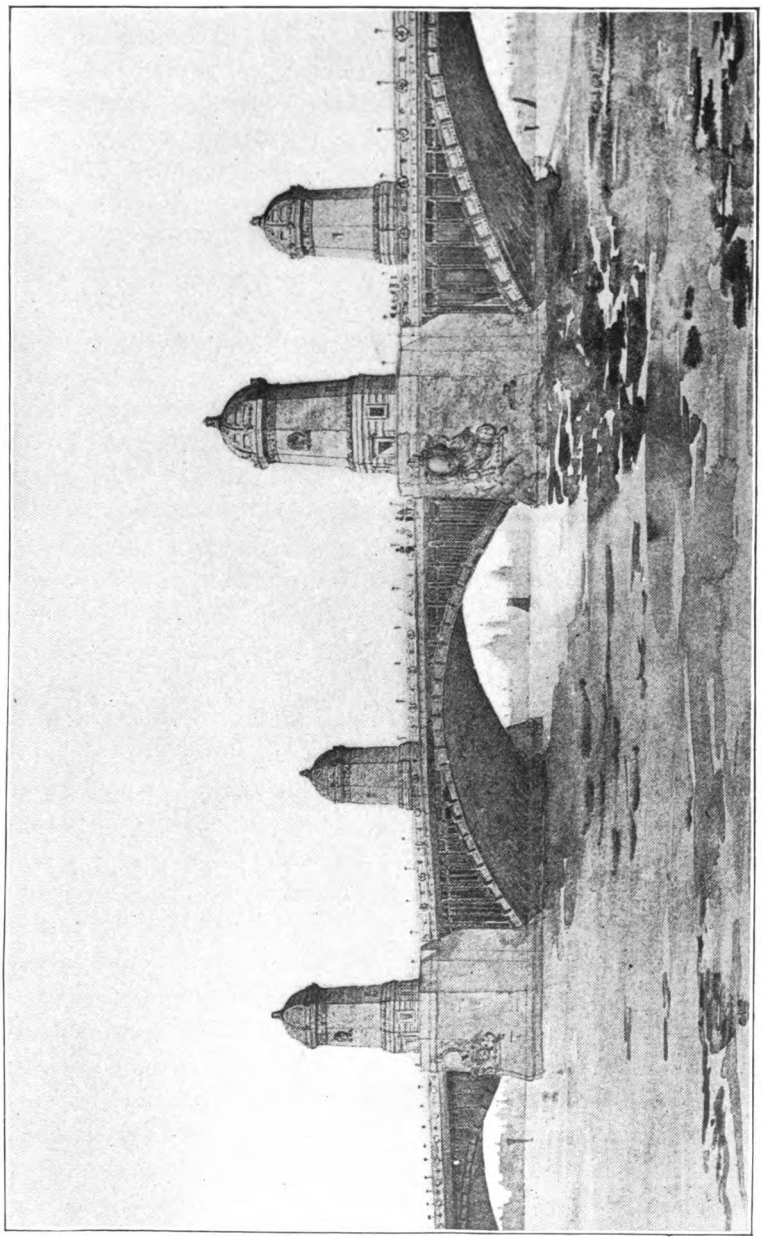
(From a lecture before the Harvard Engineering Society, March 5, 1902.)

THE Cambridge Bridge, now being built across the Charles River, on the site of the old West Boston Bridge, is expected to be not only one of the finest structures of its kind in the country, but is of particular interest as marking another step in advance, in the proper recognition by municipal authorities of aesthetic considerations in the design of public works, as well as in a hearty co-operation of the engineer and the architect, in such design.

The question of a new bridge at this point had been agitated for a number of years. It first received legislative consideration by the legislature of 1897, in connection with the general act to promote rapid transit in Boston and vicinity. The matter took definite shape in 1898, when the Legislature authorized the construction of the bridge by a commission consisting of the mayors of Boston and Cambridge, *ex officiis*, and a third permanent member, who is expected to serve throughout the life of the commission. Mr. E. D. Leavitt, of Cambridge, a well-known mechanical engineer, was chosen as third commissioner.

It was recognized that a bridge on this site should be more than a structure built merely for utility, along the lines of strict economy. The Charles River is unique among American rivers owing to the fact that its banks for more than twenty miles are public reservations. The river broadens at the lower end of this park system into a beautiful basin, which will be crossed by the new Cambridge bridge, and the day is probably not far distant when the Charles will become one of the best water parks of the world. It is for this reason that it was determined at the outset that the bridge should be of a dignified and monumental character.

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CENTRAL SPAN.

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The commission organized in the spring of 1898, and appointed William Jackson (M. I. T. '68) chief engineer, and John E. Cheney (L. S. S. Harv. '67) first assistant engineer. Mr. Jackson and Mr. Cheney are respectively city engineer and assistant city engineer of Boston. Associated with them is Edmund M. Wheelwright, a leading Boston architect. In the fall of 1898 Mr. Jackson made a trip to Europe to study noted bridges there. In Dresden he joined Mr. Wheelwright, and together they travelled in Germany, Austria, France, and England.

It is not so simple a matter to build a bridge over tide water as might be imagined. Although the bridge was authorized by the State Legislature, the details of the work were to a certain extent subject to the approval of the State Harbor and Land Commission, and of the two cities interested; but, even with the approval of the state and municipal authorities gained, nothing could be done without the consent of the United States War Department, for the Charles is a navigable waterway, and as such is under the control of the Secretary of War.

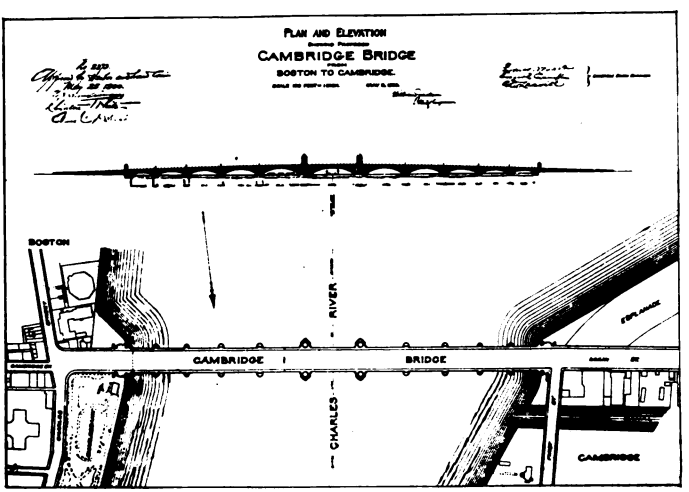
The old West Boston bridge had a draw which would allow the passage of any vessel of such size as could enter the river. The earlier studies for the new bridge were made with the idea of using a draw; and several of the preliminary designs were for a bridge of stone or steel arches with a central draw channel running through an artificial island, the latter being of structural use to resist the thrust of the arches of each half of the bridge, and available also for park purposes. These designs furnished many architectural possibilities; but it was felt that a draw of any description would not add to, but would rather detract from the beauty of the bridge. Then the question of a drawless bridge began to be discussed, not simply from considerations of appearance, but from the standpoint of public utility as well. All admitted that a drawless bridge furnished far better accommodation to highway travel; and, as far as river navigation was concerned, it was pointed out that, as practically all the up-stream shore property was to be used for park purposes, the interests of the few remaining wharf owners might be sub-

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ordinated to the great number of people who would daily use the bridge.

After a long discussion and many hearings, the Massachusetts Legislature in 1899 authorized the commission, with the consent of the United States government, to build the bridge without a draw, provided it crossed the channel at a height sufficient to furnish a clear head-room of twenty-six feet above mean high water, — this height being sufficient to allow the passage of tugs and vessels without masts.

In the summer of 1899, however, matters were seemingly brought to a standstill by the action of the Secretary of War in disapproving both the proposed island in the river and the



GENERAL PLAN.

drawless bridge project. The objection to the island was that it would interfere with the tidal flow, and it was held that a drawless bridge would be an unreasonable obstruction to navigation.

This did not, however, end the agitation for a drawless bridge. The Massachusetts delegation in Congress was appealed to; and Edgar R. Champlin, the then Mayor of Cambridge, and one of the commissioners, was delegated by the commission to

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go to Washington to advocate the drawless bridge project. As a result of Mr. Champlin's untiring efforts and as a precautionary measure, bills were introduced in February, 1900, in "both" branches of Congress, authorizing the Cambridge Bridge Commission "to construct a drawless bridge across the Charles River in the State of Massachusetts between the cities of Boston and Cambridge." The Senate bill, presented by Senator Hoar, passed both Houses of Congress, and received President McKinley's approval the following month.

Thus, after securing legislation by three successive State Legislatures, with concurrent action by the city governments of Boston and Cambridge, after complying with all requirements of State authorities, after numerous and lengthy hearings, and after a protracted controversy with the War Department, the adverse decision of which was finally overruled by Congress, the Cambridge Bridge Commission, at the end of the second year of its existence, was able to proceed with the final plans for the bridge.

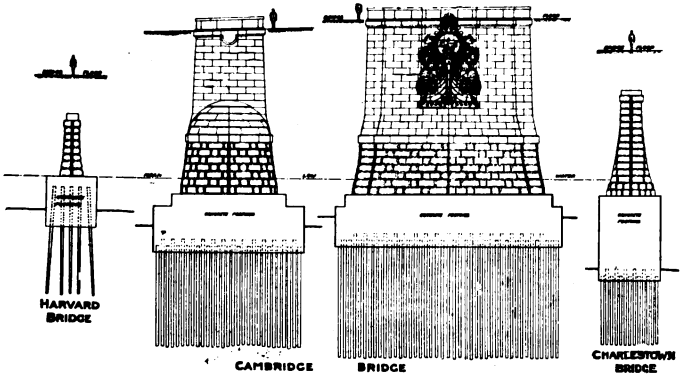
During all this time the engineering and architectural staffs had not been idle. Some thirty or forty designs had been made and carefully considered, and from these came the final design as shown in Fig. 1. The length of the bridge between abutments will be 1,767½ feet, comprising 11 spans of steel arches of 12 ribs each, with spans varying from 101½ to 188½ feet. The height of the bridge at the center is to be 48½ feet above low water, which gives, at the center span, the 26 feet of headroom at high water required by the Acts of Congress and the State Legislature.

The bridge will be 105 feet wide between railings, making provisions for four lines of car tracks, flanked on either side by a broad roadway and sidewalk. The two central tracks will be fenced for the use of elevated railway trains, but will be at the level of the roadway.

One of the features of the bridge will be the massiveness of its granite piers. End elevations of Piers 4–7 and 5–6 of the Cambridge Bridge are shown in comparison with end elevations of the largest piers of Harvard and Charlestown bridges in Fig. 2.

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The two central piers (5–6) have foundations 201 feet long by 67 feet wide, and the total distance from the bottom of the foundation piles to the tops of these piers will be 100 feet. These central piers will have at each end an ornamental stone tower 40 feet high above the roadway, and smaller stone towers will be placed on each abutment. The work will require 80,000 cubic yards of dredging, 85,000 cubic yards of Portland cement concrete, 20,000 cubic yards of granite, 25,000 piles, 150,000 barrels of cement, and 8,000 tons of steel. These quantities are for the bridge only and are exclusive of those required for its approaches.



END ELEVATIONS OF PIERS.

A wooden pile bridge of about the same capacity of the old West Boston bridge was first built across the river to accommodate travel during the construction of the new bridge.

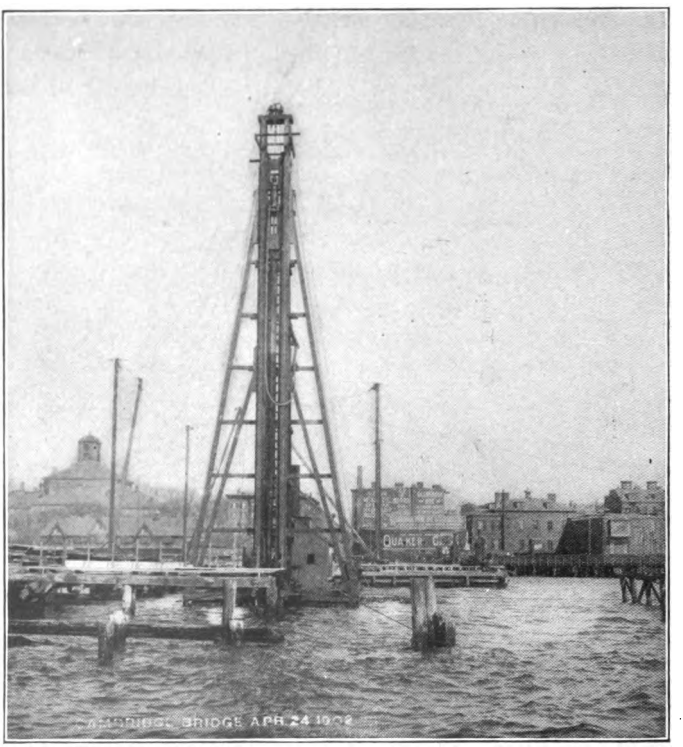
The work of building the piers was begun in July, 1900, under contract with Holbrook, Cabot & Daly, and was carried on as follows.

The old bridge was removed at the points where the piers were to be built and the areas to be occupied by the foundations dredged to a depth of from 18 to 24 feet below low water.

Such of the dredged material as was suitable for filling around the completed piers was reserved for that purpose, and the bal-

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ance carried five miles out to sea and dumped. The foundation piles were then driven to a depth of from 30 to 75 feet below low water into gravel and hard pan. The piles were driven by a steam pile driver with follower and extension gins. The weight of the hammer was 5000 pounds, the stroke 3 feet, and

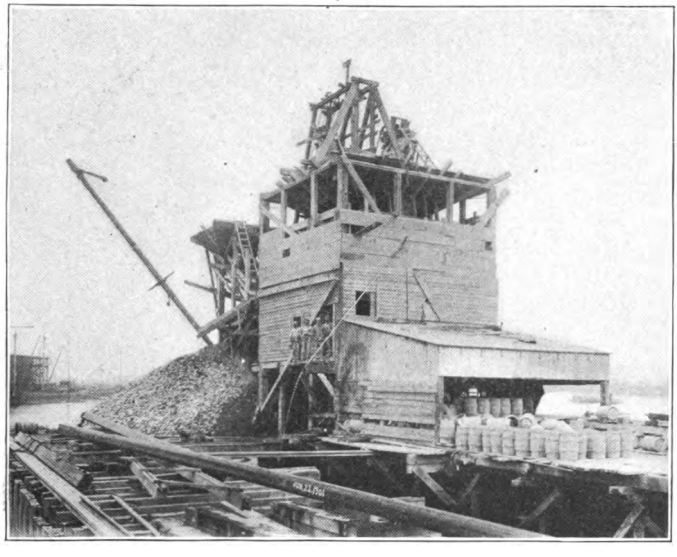


STEAM PILE DRIVER.

the number of blows per minute, 54. The weight of hammer, cylinder, etc., amounting to 13500 pounds, is applied directly to pile before and during driving. The piles, which were brought from Nova Scotia and New Brunswick, are of spruce or Norway pine from 20 to 50 feet long. They were driven in two sets, one being 2 feet higher than the other. After the first set was

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driven about 3 feet on centers, they were sawed off at the proper elevation by a circular saw mounted on a vertical shaft 60 feet long which was driven from the deck of a scow by a belt, and so arranged that the saw could be set at any depth down to 40 feet under water. The second set was then driven and sawed off 2 feet above the first. A coffer dam of 6-inch tongued and grooved yellow pine timber was then driven around the pier, the timber being generally 40 feet in length. In this and upon the top of the piles was deposited the concrete made of Portland



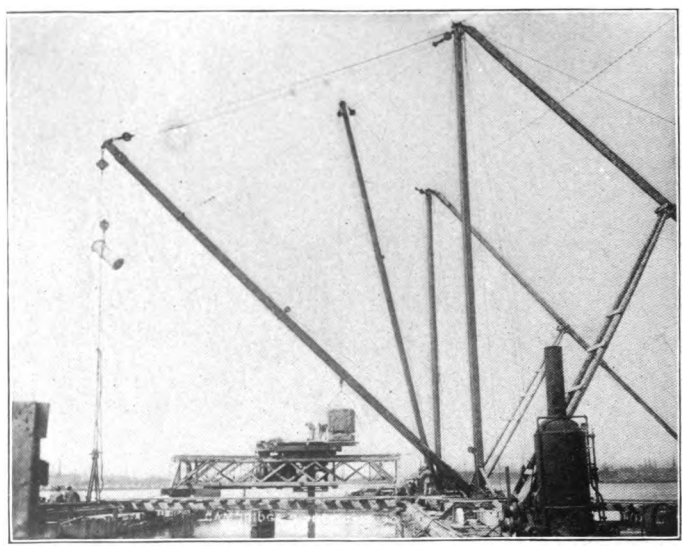
CONCRETE MIXER.

cement, sand, and gravel mixed in the proportion of 1 : 2 : 4, deposited through a tube under water to a depth of six feet below low water. The concrete was prepared by a special measuring and mixing plant shown in Fig. 4, and placed under water with the apparatus shown in Fig. 5. The average amount of concrete mixed and used per day was 156 cubic yards, and the maximum amount per day, 347 cubic yards. The coffer dam was then heavily braced, caulked up, and pumped out by very large and powerful centrifugal pumps, two of which could dis-

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charge from 20,000 to 25,000 gallons of water per minute, or over 1,000,000 gallons per hour. The rest of the work was then done in the open air with the dams free from water.

The top of the concrete foundation is at an elevation of 5 feet below water, and from that elevation the pier has a facing of heavy granite backed with concrete. The ten piers are already about two thirds completed, and work will soon begin upon the abutments.



DEPOSITING CONCRETE IN FOUNDATION.

Its cost is estimated at about $2,500,000, to be borne equally by the city of Boston and the city of Cambridge. The bridge Act provides, however, that the Boston Elevated Railway Company "shall pay towards the construction of said bridge such portion thereof as shall be rendered necessary by reason of its being of additional size and strength for the use of the elevated railroad." The amount to be paid by the railway company is to be determined by a commission appointed for the purpose.

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WIND STRESSES IN RAILWAY BRIDGES.

LEWIS JEROME JOHNSON, A. B., C. E.

Assistant Professor of Civil Engineering.

WIND forces, so far as specially provided for, are horizontal forces coming to bear on a bridge structure, either directly or through their effect on the side of a moving train. The problem now in hand is to estimate the stresses arising from these forces.

For this purpose it is useful to observe that the whole bridge structure (exclusive of the web members of the main trusses) may frequently be regarded as consisting of a pair of cantilevers, of rectangular outline, one at each end of the span, supporting two trusses in horizontal planes, one truss coming to bear at the outer ends of these cantilevers, the other at or near the inner end. These cantilevers consist of the two end posts of the main trusses rigidly braced together, and securely anchored to the abutments at their lower ends. In a through bridge the bracing between the end posts can be between the upper ends only, and is then given the name of *portal strut* or *portal bracing* and the whole cantilever is then called the *portal* of the bridge. Such a portal is shown in Fig. 1. In a deck bridge, this bracing can be placed in its natural position along the diagonals of the rectangle and the cantilever will appear as in Fig. 2. This frame performs the same functions as the portals of a through bridge and may be understood to be included in the term portal, in what follows.

The wind-forces on the bridge are transmitted to the portals by means of the horizontal trusses above mentioned. The truss at the top or outer end of the cantilever is composed of the two main upper chords and a system of struts and diagonals specially added; that at the bottom, similarly, of the two main bottom chords and specially added web members. The floor beams can usually be made to do duty as the struts of one

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of these trusses,— of the lower horizontal truss in through bridges, of the upper in deck bridges. These systems of horizontal bracing are called the *lateral systems* of the bridge, upper and lower respectively, on account of their office being to resist sidewise or lateral forces, principally from the wind, but sometimes from other causes, such as shocks due to the unevenness

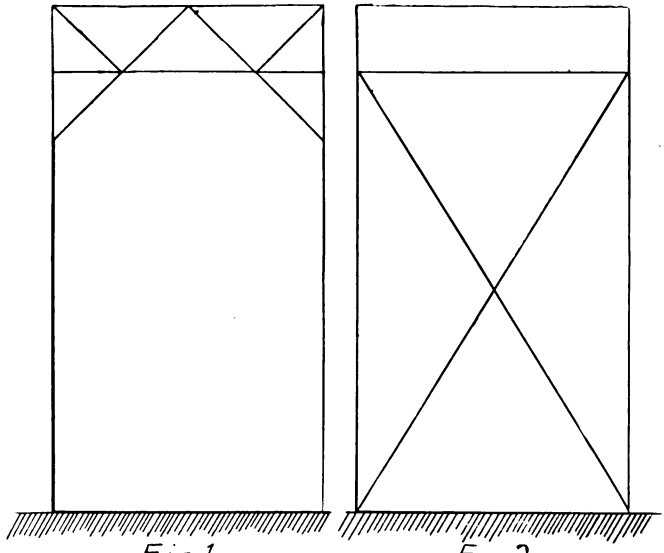


Fig 1 Fig 2

of the track, or centrifugal force, if the bridge be upon a curve. It will be sufficiently accurate to take the wind pressure on the whole bridge as being transmitted to each portal in two components, one in the plane of each lateral system. One of the lateral systems — the one nearer the bridge floor — will in addition have to resist the whole wind pressure on the train as a uniformly distributed moving load, and transmit its effect to the portals and to the anchorages.

The wind pressure on the train, acting out of the plane of a lateral system, affects stresses outside that system, in fact, those in the main trusses, the effect being to diminish the

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vertical train-load stress on the windward truss and increase it on the leeward truss.

The wind will accordingly have to be considered in relation to the two kinds of effects which it tends to produce upon the bridge: (1) to deflect or shove it bodily to leeward, and (2) to overturn it.

The complete computation of the wind stresses for a through-bridge involves five cases of loading for four different frames, viz.:

(*a*). Upper lateral system, with bridge subject to full side-wise wind-pressure on its own structure.

(*b*). Lower lateral system, with bridge subject to the same load as in (*a*).

(*c*). Lower lateral system for wind-pressure upon a passing train.

(*d*). Main trusses for effect of preceding load in increasing stresses in the leeward sides of the main trusses, while decreasing them in the windward sides.

(*e*). Portals (and lower chords) for maximum reactions from the upper and lower lateral systems.

For a deck bridge, the cases are the same except that in steps (*a*), (*b*), and (*c*) the word "lower" and "upper" would take the places of "upper" and "lower" respectively.

The method of operation will best be made clear by taking a numerical case and making for it the needed computations. These can be made for the last step by the interested reader without difficulty with the aid of §§ 115, 116 of Johnson, Bryan and Turneaure's *Modern Framed Structures*. That step will consequently receive no further attention in this article, but the complete treatment of the four remaining steps may well be illustrated here. A through bridge will be selected for this purpose, but there should be no difficulty in inferring correctly from this how a deck bridge should be treated.

Take, for example, a through bridge, Fig. 3, of 150 ft. span, with trusses, of the Pratt type, 30 feet deep, of six equal panels. and with inclined end posts as usual. Assume the two main trusses of the bridge 16 feet apart on centers, thus implying a single track road.

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The lateral forces to be resisted will be assumed in accordance with § 24 of Cooper's *General Specifications for Steel Railroad*

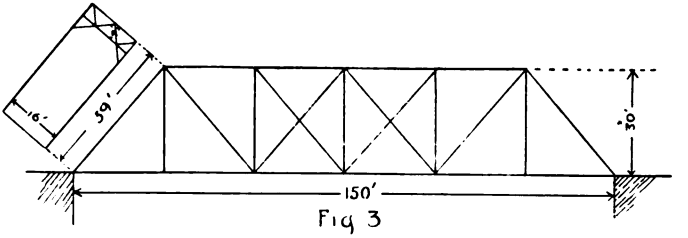


Fig 3

Bridges and Viaducts, 1901 edition, which runs as follows:

"To provide for wind strains and vibrations from high speed trains, the top lateral bracing in deck bridges and the bottom lateral bracing in through bridges, shall be proportioned to resist a lateral force of 600 pounds for each foot of the span; 450 pounds of this to be treated as a moving load, and as acting on a train of cars, at a line 6 feet above base of rail."

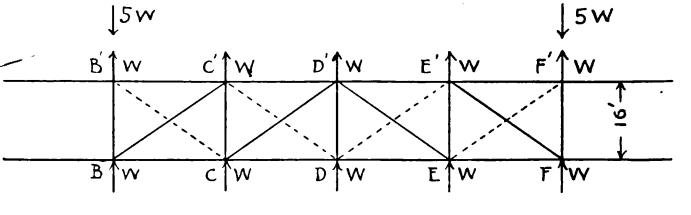


Fig 4

"The bottom lateral bracing in deck bridges and the top lateral bracing in through bridges, shall be proportioned to resist a lateral force of 150 pounds for each lineal foot for spans

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up to 300 feet, and 10 pounds additional for each additional 30 feet."

Hence it follows that in steps (a) and (b) the load to be taken is 150 pounds per lineal foot, in step (c) 450 pounds per lineal foot, and in step (d) some value derived directly from 450 pounds horizontal pressure per lineal foot. In steps (a) and (b) the load will be considered as coming to the lateral trusses in equal shares from the two main trusses.

Step (a) involves a parallel-chord truss of 100 feet span, 16 feet deep, consisting of four equal panels and loaded as shown in Fig. 4 where $W = \frac{25 \times 150}{2} = 1875$ pounds.

The dotted diagonals are out of action when the wind is in the direction shown. In step (b) the truss is a similar one but of 150 feet span, and of six equal panels loaded as shown in Fig. 5

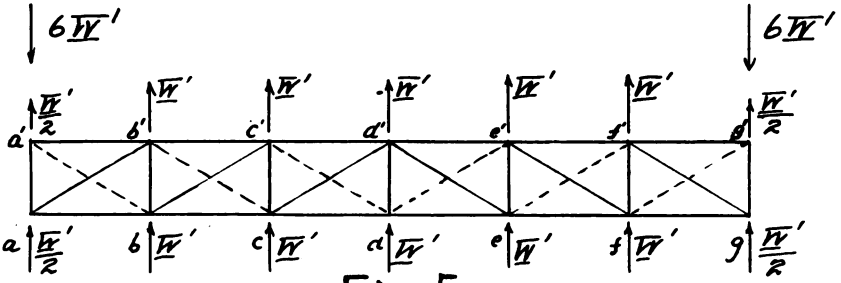


Fig. 5

where $W' = \frac{25 \times 150}{2} = 1875$ pounds.

The resulting stresses in steps (a) and (b) are conveniently found in tabular form from the bending moments and shears, bearing in mind that the stresses in the lateral posts will be equivalent to the numerical value of shears, those in the lateral diagonals to these values into the secant of the inclination, θ, of the diagonals to the external forces, and the chord stresses to the

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bending moments divided by the depth of the trusses. This work for both steps noting that $\sec\theta = \frac{\sqrt{25^2 + 16^2}}{16} = 1.85$, will appear as follows:

Stresses in Upper and Lower Laterals — Fixed Wind Loads

Panel of Panel point	Forces	V Shear in terms of W	V Shear in Semi-Tons	Web Stresses: Diags Vsec θ 1.85 V	Web Stresses: Verts	Web Stresses: Member	Vd (d = panel length)	B.M. in terms of Wd	Chord Stresses: Stress Ft. Wkg. 4950 lbs.	Chord Stresses: Member	
BB′	3W̄				+75	BB′				B′C′	UPPER LATERAL SYSTEM
BC		3W̄	5625	-104		B′C / BC	3W̄d				
CC′	-2W̄				+3.75	CC′		3W̄d	±88	B′C′ / C′D′	
CD		W̄	1.275	-35		C′D′ / D′C	W̄d				
DD′	-2W̄				+19	DD′		4W̄d	±11.7	C′D / DE	
DE		-W̄	-1.875				-W̄d				
EE′	-2W̄							3W̄d	±88	E′F / D′E	
EF		-3W̄	-5675				-3W̄d				
FF′	-3W̄									E′F′	
aa′	5W̄′				+10.31	aa′			0	a′b′	LOWER LATERAL SYSTEM
ab		5W̄′	9375	-17.4		a′b′ / a′b	5W̄′d				
bb′	-2W̄′				+75	bb′		5W̄′d	±147	ab / b′c′	
bc		3W̄′	5625	-104		bc′ / b′c	3W̄′d				
cc′	-2W̄′				+3.75	cc′		8W̄′d	±235	bc / c′d′	
cd		W̄′	1875	-35		cd′ / c′d	W̄′d				
dd′	-2W̄′				+19	dd′		9W̄′d	±264	cd / dc	
de		-W̄′	-1875				-W̄′d				
ee′	-2W̄′							8W̄′d	±235	d′e′ / ef	
ef		-3W̄′	-5625				-3W̄′d				
ff′	-2W̄′							5W̄′d	±14.7	e′f′ / fg	
fg		-5W̄′	-9375				-5W̄′d				
gg′										f′g′	

In step (c), as already stated the load is a moving one of 450 pounds per lineal foot. This will be assumed to be applied entirely on the windward chord of the lateral truss, though it is actually applied to the floor beams at points between the two chords of that truss. The lateral truss concerned is that used in step (b) except that, if a-g be the windward chord, the diagonals which will be subject to the maximum tensions as a train moves across the bridge from right to left are those shown in Fig. 6.

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The maximum chord stresses will occur when the train covers the whole span. The forces acting on the truss will then be those of Fig. 6, and the chord stresses found for the left hand half of that truss will be the actual maximum stresses sought, not

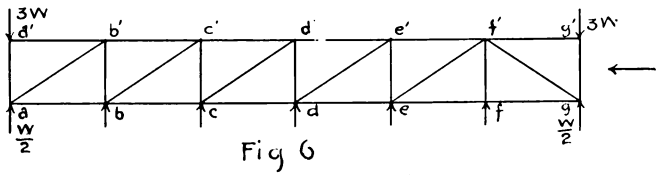


Fig 6

only for chord bars on that side of the center of the span, but for symmetrically situated ones on the other side of that center.

For determining the maximum shears in the successive panels it will be assumed that joints receive full loads or none at all. This method errs slightly, but not objectionably, in that it gives shears somewhat in excess of actual maximum values.

The maximum shear in each panel will then be taken as that which will occur when there are full loads of W at all joints at the right of the panel, but none elsewhere. In this step W = $25 \times 450 = 11{,}250$ lbs.

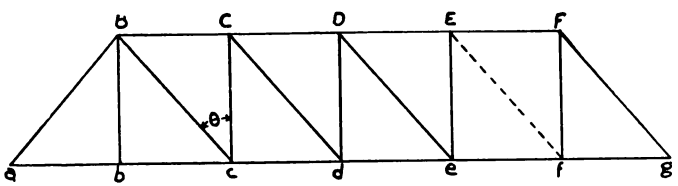


Fig 7

In step (d) we have to apply the same methods to a main truss taking diagonals as all sloping downward toward the approaching train as shown in Fig. 7. The load per running

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foot is, however, a different one, and is estimated as follows. Assuming the base of the rail to be five feet above the plane of the lower lateral system, the arm of the couple formed by the pressure on the train and the resistance of the lower lateral system is 11 feet. The arm of the apposing couple offered by the two main trusses of the bridge is 16 feet. The resulting increase of load on the leeward truss and decrease of load on the windward one is $\frac{450 \times 15}{16}$ or, to the nearest pound, 422 pounds, per running foot. This may be expressed as $\pm$ 422 pounds, the plus sign pertaining to the leeward truss, the minus sign to the windward truss, and the value of the panel loads becomes $25 \times \pm 422$ or $\pm$ 10550 pounds.

The stresses for steps (c) and (d) are worked out in the following table, the methods being identical for the two, and secant θ in step (d) being $\frac{\sqrt{30^2 + 25^2}}{30} = 1.30$.

Stresses from Moving Wind Loads.

	Panel or Panel point	Max BM in terms of Panel load W & Panel length d	Same in ft lbs in terms of W	Same in Tons	Max Shear in terms of W	V Max Shear in Tons	Diags. V sec θ	Verts. V	Member	Stress Σ	Member
Lower Lateral System (Steps c and d) 11250							sec θ=1.85			M/16	
	a a′							+33.8	a a′		a b
	a b				5W̄ 5/12 = 2.5W̄	28.1	52.0		a′b		
	n b	5/2 W̄ d	62.5W̄	703.1				+18.8	b b′	±43.9	a′b′ or b c
	b c				4W̄ 5/12 = 1.67W̄	18.8	34.6		b′c		
	c c′	5/2 W̄. 2d − W̄d	100 W̄	1125.0				+11.25	c c′	±70.3	b c or c d
	c d				3W̄ 4/12 = 1W̄	11.25	20.8		c′d		
	d d′	5/2 W̄. 3d − 3W̄d	112.5W̄	1260.1				+5.6	d d′	±79.3	c′d′
	d e				2W̄ 3/12 = .5W̄	5.6	10.4		d′e		
	e f				W̄ 2/12 = .17W̄	1.9	3.5		e′f		
	f g										
Main Trusses (Overturning effect) 10550							sec θ=1.30			M/30	
	a							±26.4	a		
	a b				2.5 W̄	26.4	∓34.3		a B		
	b	5/2 W̄d	62.5W̄	659.4				∓10.6	b B	±22.0	a b & b c
	b c				1.67 W̄	17.6	∓22.9		B c		
	c	5/2 W2d − W̄d	100W̄	1055.0				∓10.0	c C	±35.2	B C & c d
	c d				1.00 W̄	10.6	∓13.8		C d		
	d	5/2 W̄ 3d − 3W̄d	112.5W̄	1186.8				∓5.3	d D	±39.6	C D
	d e				0.5 W̄	5.3	∓6.9		D e		
	e							∓1.8	e E		
	e f				0.17W̄	1.8	∓2.4		E f		
	f g										

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Sometimes, as in the deep trusses of long spans, when opposite posts of the main trusses are rigidly braced together, each pair of posts with such bracing becomes in effect a cantilever similar to the portals proper and the load coming to one lateral system is thus transferred, to a greater or less extent, in a vertical plane directly to the other system. One system is thus relieved at the expense of the other. The extent of this direct transference of load from one system to the other would depend largely on the conditions in any special case, and when once decided upon, the computations would proceed along the general lines above laid down.

In conclusion, the reader should be reminded that the loads assumed in the foregoing numerical example were taken at a figure believed to be high enough to allow not only for wind pressures pure and simple, but also to lead to the provision of the requisite strength to resist satisfactorily the tendencies to horizontal vibrations arising from the heavy, high speed trains of the present day. Indeed these horizontal vibratory tendencies are coming to be regarded as so serious that it is probable that in the best modern practice that they alone would be held to justify the assumption of stresses as great as those calculated above even in the least exposed situations in the least tempestuous climates.

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THE RAPID TRANSIT SUBWAY IN NEW YORK.

EDMUND M. BLAKE, '99.

(From a lecture before the Harvard Engineering Society, May 9, 1902.)

THE history of the efforts to secure Rapid Transit in the City of New York dates back to 1866 when, at the close of the Civil War, the City began its marvelous growth. In that year, when the total population of what is now Greater New York was about 1,200,000 people, and there were only about 100 miles of single track horse-car lines, Gen. Edward S. Serrell proposed a triple structure to be built from Battery Park to Kingsbridge; the upper one, an elevated road for express passenger traffic, a surface line for local passenger traffic, and an underground road for freight traffic. This scheme failed as did also the plan of the Beach Pneumatic Underground Railway Company in 1868, although about 200 feet of the Beach pneumatic tube, with a diameter of 8 feet, was built under Broadway near Warren Street. It was not until 1871, however, that the real agitation for an elevated line began. This resulted in the Rapid Transit Commission of 1875, under which the development of the present Elevated system commenced. In 1879 the West Side Elevated Co. and the Metropolitan Elevated Co. were merged into the Manhattan Railway Company which is the Company controlling the present elevated system in New York City. This Company operates over 36 miles of track.

While this elevated development was going on, but slight consideration was given to the many underground projects brought forth. In 1888, Mayor Abram S. Hewitt, in his message, outlined a comprehensive plan for an underground system and in 1890 the need of better facilities for Rapid Transit was so apparent that Mayor Grant appointed a Rapid Transit Com-

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mission. Their first plan was to buy a right of way through the blocks along Broadway, construct an elevated road and then rebuild the blocks with fire-proof buildings. This proved to be far too expensive and when, in 1891, the New York Legislature passed the first Rapid Transit Act and William Barclay Parsons was appointed Chief Engineer, the Commission virtually adopted Mayor Hewitt's plan of 1888. The plan chosen ran up Broadway to City limits near Spuyten Duyvil Creek, with a branch at Union Square running up Madison Avenue under the Harlem River into the Bronx. This plan passed the approval of all the parties required by law, and the objections of the property owners were over-ruled by a special Commission appointed by the Supreme Court; but when the bids were opened on December 29, 1892, no bona fide bid was presented, since the plan, specifications, terms of sale, and the Act itself were found to be faulty. Through the efforts of the Chamber of Commerce an amended Rapid Transit Act was passed by the New York Legislature in 1894, the most important change being that the citizens of New York were to decide by vote whether the road should be built by the city or by private capital. Mr. William B. Parsons was again appointed Chief Engineer and was sent to Europe to study the foreign underground systems.

Following his report on those systems, in October, 1894, the citizens voted at the November elections to build the road at an expense to the City of about $50,000,000 and new plans were made. These failing to receive the necessary indorsement, the plan of the 1891 Commission was re-adopted in February, 1895, practically in its original form. A Commission appointed by the Supreme Court over-ruled the objections of the property owners, but the Supreme Court itself reversed the decision of its Commission on the ground of the great and uncertain cost of the plan and the fact that the City had very nearly reached its constitutional debt limit. As a result, in August, 1896, new plans were made for a road to cost $30,000,000. The new route ran up 4th Avenue to 42nd Street, branching there to the west and running up Broadway to Kingsbridge. The east side branch

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continued up Park Avenue, going under the Harlem River and into the Bronx. When the usual objections had been over-ruled and everything looked like success, Mayor VanWyck announced that the City was too poor to build and in May, 1898, the City Comptroller reported that the City had reached its constitutional debt limit. This killed the Act for some time but at the close of the Spanish war it was seen that such a financial condition of the City made ALL improvements impossible. Accordingly the tax assessment was raised, the Commission, meantime, having declined to accept an offer made by the Metropolitan Street Railway Co. to build the underground road provided the City would grant them a perpetual franchise.

At last, in November, 1899, after nearly a decade of planning, controversy and litigation, the Commission advertised for bids on a revised plan and on January 15, 1900, two proposals were received, one from Mr. J. B. McDonald for $35,000,000; the other from Mr. Andrew Onderdonk for $39,300,000. Mr. McDonald's bid was accepted and in February the New York Legislature authorized the City Comptroller to issue bonds without the concurrence of the Municipal Assembly. Accordingly, on March 2, 1900, the Board of Estimate and Apportionment ordered the issue of $36,500,000 of bonds.

The conditions and qualifications of this contract are worthy of note since it is the largest individual contract ever let in the history of municipal engineering. Mr. McDonald was required to furnish a bond for $1,000,000; The Rapid Transit Subway Construction Company, financed by August Belmont and Co. and organized to take over the contract from Mr. McDonald, was required to furnish a bond for $4,000,000 and to make a cash deposit for $2,000,000; and the Surety Companies were required to furnish a bond for $1,000,000. These bonds were required in order to assure the faithful performance of the contract. The contract itself, in addition to the "Agreement for Construction" in accordance with the terms of the Specifications, contains the terms for a "Lease," under which Mr. McDonald or his legal representatives are allowed to operate the completed road for a period of 50 years at the end of which

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period the "Lease" is to be surrendered to the City, with the proviso that it may be extended for 25 years more if desired. During these 50 years, rental is to be paid the City as follows: an annual sum equal to the annual interest on all the bonds issued and a further sum equal to 1% of said bonds. There is a slight change in these conditions during the first ten years. If the "Lease" is continued for the additional 25 years, the above terms of rental will hold.

To sum up the Contract briefly, Mr. McDonald will receive pay in long term bonds of the City of New York for the construction of the road, he agrees to equip it with rolling stock and motive power and is allowed to operate it for 50 years, paying an annual rental to the City for this privilege as stated above. At the end of 45 years, it is calculated that these payments will have paid off the bonds and when the "Lease" expires, the City agrees to buy up the rolling stock and other equipment at a fair price to be agreed upon by arbitration. Thus it is seen that New York City will become the owner of a Rapid Transit Subway without any cash outlay except for equipment, and also that it assumes no financial responsibility except to stand behind the bonds in case the Contractor fails or is unable to pay the interest on them. On the other hand, Mr. McDonald is enabled to secure money at a lower rate than if he used his own credit to issue stocks and bonds, the Subway Construction Company saves him the trouble of financing the scheme and when he operates it will not be under a franchise that might be altered by legislation but under a strictly defined contract which cannot be affected by laws. Altogether, it is a most remarkable contract from a legal, financial and municipal point of view.

The Subway, in process of construction at the present time, starts at City Hall with a big loop between City Hall and the Post Office Building, then runs in a four track section up Centre, New Elm, and Great Jones Streets, enters 4th Avenue near Union Square and runs up 4th Avenue to 33rd Street. Here the four track section divides into 2 two track sections, passing under and outside of the present 4th Avenue tunnel to 41st

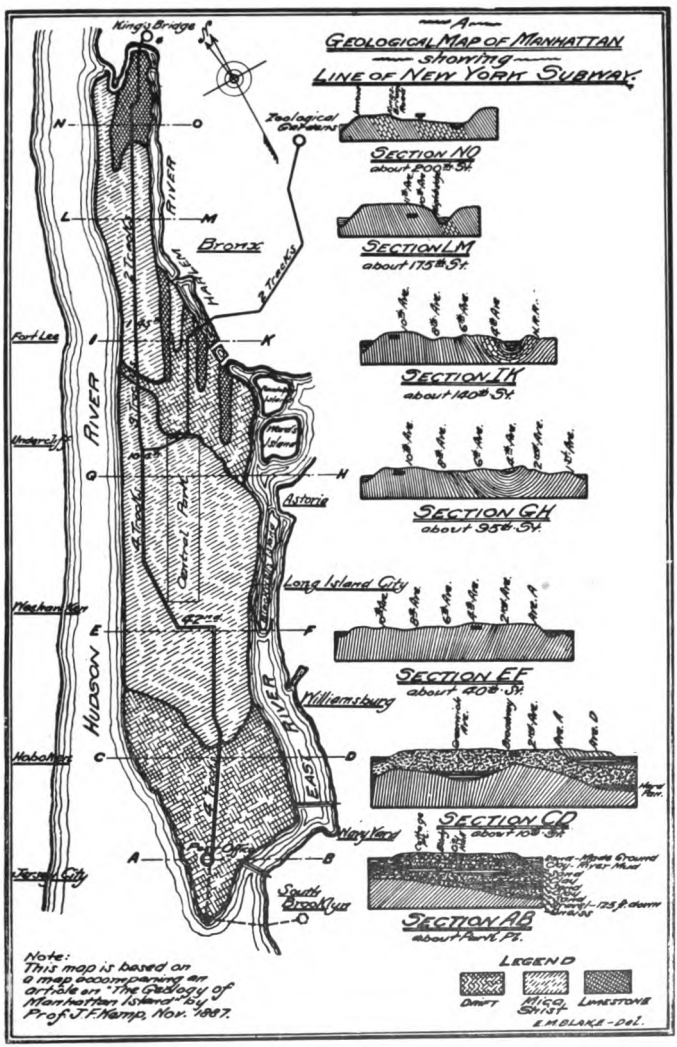
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Street. At this point, the two separate tunnels unite once more into a four track section and the road then passes by a sharp curve on to 42nd Street, through that crowded thoroughfare to Broadway and then follows Broadway up to about 97th Street. So far the section has been of four tracks, the two middle ones for express trains and the two outer ones for local trains, except near 14th Street where a fifth track is added in order to start extra trains from the shopping district in the rush hours of the day. Near 97th Street, the two express tracks begin to depress and at 104th Street they leave Broadway on a sharp curve, pass under 104th Street and the northwest corner of Central Park in a deep tunnel, run up Lenox Avenue, pass in a concrete tunnel under the Harlem River and after entering the region of the Bronx, emerge from the ground on to an elevated structure which runs up to the Zoological Gardens. Going back to 104th Street, the two local tracks, uniting with a third track, pass on up Broadway, cross Manhattan Valley on a steel viaduct, enter the ground again and run up to 145th Street. At this place the Subway will contain eight tracks for nearly half a mile for the storage of cars. Going north from 145th Street, a two track section runs up Broadway, enters a deep rock tunnel at 157th Street, emerges near 190th Street and runs up Kingsbridge Road on an elevated structure, crossing the Harlem Ship Canal and having its terminal at Kingsbridge.

The line, in plan, resembles roughly a letter "Y," the stem, a 4 track section 7 miles in length, the east branch, a 2 track section 7 miles in length, the west branch 7 miles in length of which 2 miles is a 3 track section and 5 miles a 2 track section. Thus the entire line is approximately 21 miles long with about 60 miles of single track. When the whole excavation is completed, 3,000,000 cubic yards or 81,000,000 cubic feet of earth and rock will have been taken out. This total excavation is equivalent to a tube 6 feet in diameter running from Boston to a point near Cleveland, or a distance of 542.6 miles, and of this length, the portion from Boston to a point near Syracuse would be solid rock. In this tunnel are to be erected 65,000 tons of steel, all of which, except on the elevated sections, will be

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encased in concrete and a waterproof covering. Nearly 500,000 cubic yards of concrete and 775,000 square yards of waterproofing will be laid.



In construction details, three main types are employed, viz.: the elevated structure, similar to the New York and Boston ele-

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vated work and requiring no description here; the solid concrete arch tunnel section, needing no description; and the steel and concrete construction which will be briefly described. This construction is as follows: — when the excavation in rock has been carried to subgrade, a 7″ concrete floor, mixed in the proportions of 1 to 3 to 5, is laid. This thickness is increased in earth excavation at some places met with from City Hall up to about 10th Street. On top of this bottom course of concrete is laid 3 or more ply water-proofing, depending on the nature of the excavation. This water-proofing is put on as follows: — first, the concrete surface is covered with a thick coating of boiling asphalt; on this is laid asphalted felt paper, with a prescribed lap of at least one foot; between each layer of felt is applied the boiling asphalt and the top is also covered with the same material. When this water-proofing is completed, another floor course of 7″ of concrete is laid, mixed in the proportions of 1 to 3 to 5. In the standard construction for four tracks, this floor is 54 feet 4 inches in width and previous to placing the concrete, a tile drain is laid along the centre lines of the two outer tracks. This subdrain, set in the bottom course of concrete, and below the water-proofing, varies in size from a 6″ to a 10″ pipe according to the nature of the soil, and from it at irregular but short intervals, 3″ or 4″ lateral tile drains run transversely to the side of the excavation to collect any water outside the walls. At intervals of about 300 feet, sumps are built in the floor of the outer tracks so that surface water collecting for any reason in the Subway may find an easy runoff to the drains. At the valleys in the track grades, similar sumps built in the floors of the middle tracks, connect by laterals with the main drains. The water collecting in the main drains is led or pumped at proper intervals into the City sewers where a ready connection can be made.

After completing the foundations, a 4″ course of hollow brick is laid for the side walls. These bricks are used in preference to regular brick for the purpose of making them act as feeders to the lateral drains. The object of this outer wall is not to add strength to the body of the Subway but rather to furnish

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an outside protection against any future excavation and against backfilling for the vitrified tile ducts carrying the cables. The floor waterproofing is next carried up in a 2 ply course on the face of this brick wall and the 4-way tile ducts are laid against it, a tier of sixteen ducts on each side of the Subway, breaking joints and each joint wrapped around with linen cloth soaked in grout, and about $\frac{1}{4}''$ of Portland cement mortar laid between the tiers. Each duct has four $3\frac{1}{16}''$ holes in which 3″ cables for power and illumination are to be carried and at intervals of about 350 feet manholes are built outside of the Subway structure at which places the cables may be drawn through. Single ducts cross the structure transversely at stated intervals.

With the ducts in place, we come to the erection of the steel bents. These consist of two I-beam side columns, set on a 6 ″ side bench of concrete and anchor-bolted in place; three compound centre columns, made up of 4″ bulb angles and plates, called "bulb angle" columns, set on 2′–3″ by 2′–3″ by 12″ footing stones and anchor-bolted in place; four I-beam roof beams varying in size according to the depth of cover and riveted to splice-plates on the column caps; and eight knee braces riveted to the columns and roof beams. The side columns are either 12″ or 15″ I-beams and the roof beams vary from 15″ I-beams to 36″ girders. This is for the standard four track section which, of course, is varied at the stations. These bents are erected 5 feet centre to centre and when riveted, the roof beams are connected with $\frac{7}{8}''$ tie rods.

Wooden forms, built on circular arcs, are next fastened to the side columns and to the roof beams and the concrete for the side walls and roof is carefully tamped in place, mixed in the proportions of 1 to 2 to 4. The waterproofing of the side walls is then continued up over the roof in a 3 ply layer and a protective cover of three inches of concrete is laid over this on top of which the backfilling is placed.

Such, in brief, is the general structure of the standard four track section. The main difficulty met with in constructing it in the field is the necessity of building small, detached sections of it at a time and connecting them up as the work goes on. In

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excavating and preparing for this construction, many serious difficulties are met with, among them the support of water and gas mains, electric ductways, sewers, 12.5 miles of which are either diverted or relaid outside of the Subway, the support of the heavy trolley track foundations, the support of the Elevated structure while passing under it at 42nd, 53rd, and 65th Sts., the support of the Columbus monument at 59th Street under a part of which the Subway passes directly, etc. All of this work is required to be done with a minimum of inconvenience



SUPPORT OF ELEVATED STRUCTURE ON 65TH STREET.

to residents along the line and a minimum of interference with traffic. By far the larger part of the excavated material is carted to the docks along the North River and towed out to sea in scows. Some of the rock is crushed on the line of the work and used for concrete, but most of it, a soft, micaceous gneiss, is too poor for concrete. Earth excavation is used for backfilling as the work advances. Most of the rock drills and hoisting engines for derricks and cableways are driven by compressed air, 9 different compressor plants having been con-

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structed at such points along the line as to give an economical distribution of power.

A brief word may be added on the organization of the Rapid Transit Commission and of the Contractor's force. Mr. Wm. Barclay Parsons, a graduate of Columbia University, is the Chief Engineer of the Commission and Mr. George S. Rice, a graduate of the Lawrence Scientific School, Harvard University, is the Deputy Chief Engineer. There is a Chief Inspector of Designs and a Chief Inspector of Materials. The line is divided into four divisions over each of which is a Division Engineer. There is also the Sewer Division, having charge of the sewer diversion of the whole line. In addition, there are at present about 300 assistant engineers, rodmen, axemen and inspectors, appointed under Civil Service rules, about 75% of them being college graduates. The Lawrence Scientific School is represented by 10 men. The object of this Commission is to safeguard the interests of the City by seeing that the Specifications are carried out in detail. Among the duties of the engineering force may be mentioned the following: laying out the original base lines and referencing the stations, taking the complete topography and cross-sections of the streets, describing in detail the condition of sidewalks and fronts of buildings, taking exact elevations on the water tables or foundations of all buildings along the line, calculations in preparation for field work, giving in the field lines and grades for excavation, concrete, brick walls, waterproofing, steel bents, sewers, pipe lines, sumps, drains and manholes, and making up monthly estimates from field measurements upon which, as a basis, the Contractor is paid. The monthly payments for the whole line average about $1,000,000, and the cost of supervising the work so far has been about 4%.

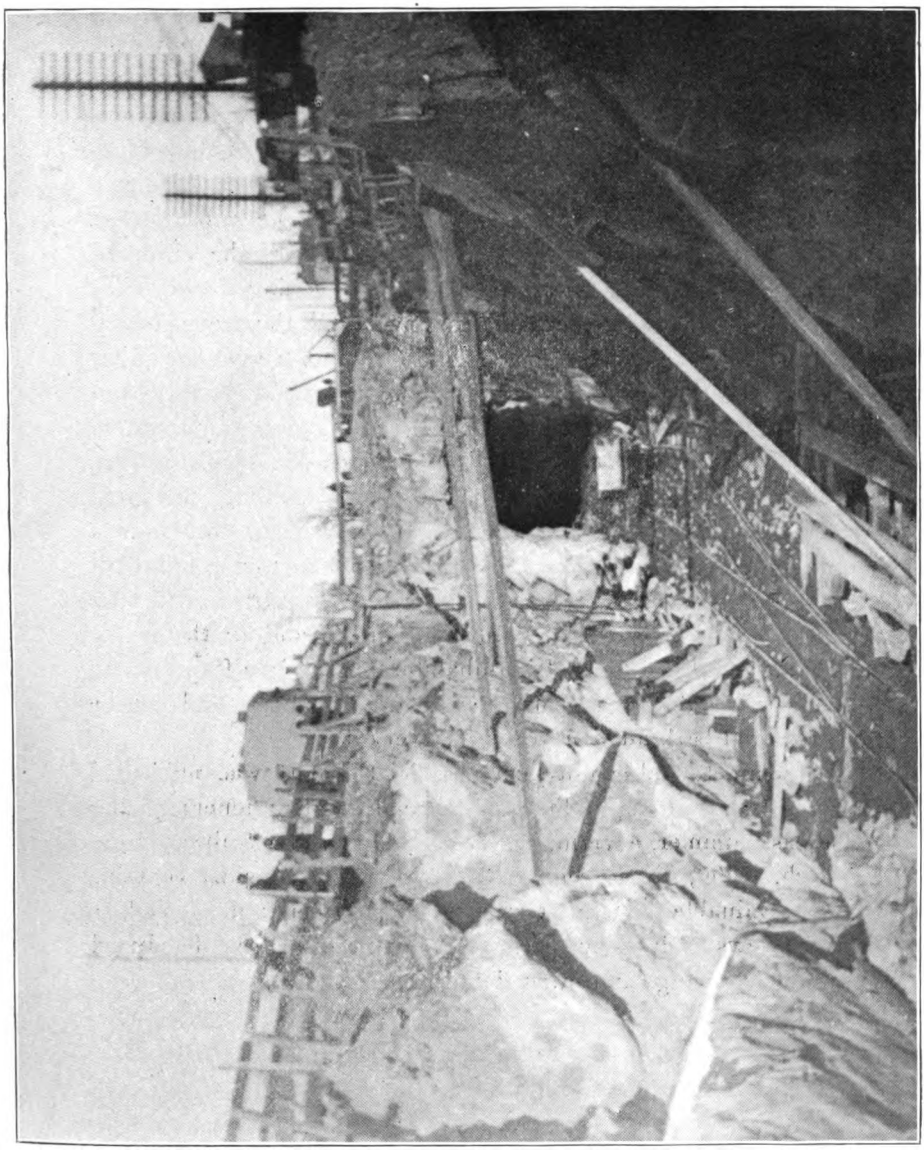
The four Divisions of the road are sub-divided, into 17 sections and Mr. McDonald sublets the work on these 17 sections to 12 different Sub-Contractors. He gave the contract for the waterproofing to the Sicilian Asphalt Paving Company and at present, the steel erection for the entire line is done by the Terry and Tench Construction Company. The Sub-

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way Realty Company has been organized to buy up real estate along the line when necessary and it is said that about $5,000,000 has already been spent in this way, largely for buildings partly damaged by explosions or cave-ins. The Subway Operating Company has also been organized to operate and equip the line when completed. The power is to be electricity with the third rail system and a big power house has been started on 59th St. on the North River. Express trains are to be run at the rate of 40 miles an hour, making the distance from 104th Street to City Hall in about twelve minutes. The cars at present being designed by the Wason Company of Springfield, Mass., are to be 51 feet in length and will have a minimum clearance on the sharpest curve of 3¼ inches. For ventilation, dependence is being placed upon the motion of the cars and the openings at the stations, although the duct manholes offer opportunities for the installation of electric motor fans if necessary. The local stations come about every ⅓ of a mile and the express stations about every 1½ miles. The express stations are located at City Hall, 14th Street, 42nd Street, 72nd Street, 96th Street, 116th Street and 145th Street. At these points, which are combined local and express stations, cross-overs will be built so that passengers may transfer from a local train to an express and vice versa. The largest station will be the so-called "theatre station" at the corner of Broadway and 42nd Street, and perhaps the most interesting station will be the one at 167th Street on Broadway where the station platform will be 115 feet below the surface of the street above and will be reached by double express elevators. This section of the Subway, about 2¼ miles in length, is a concrete arch tunnel cut through the solid rock and will be the second longest passenger tunnel in the United States.

The construction of this Subway, giving employment to about 10,000 men for a period of probably four years, although it has met with several serious accidents in bursting water mains, settling foundations, and explosions, of which the Park Avenue explosion has been the most notable, is well ahead of contract time and Mr. McDonald has assured the citizens of

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ENTRANCE TO DEEP TUNNEL, 157TH STREET.

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New York that, barring serious and unexpected delays, he will have cars running from 104th Street to City Hall by Christmas, 1903. The date of the expiration of the contract is September, 1904.

This road is the first of a comprehensive underground system for Greater New York in which system are included the Brooklyn extension and the East Side branch with terminals for the Brooklyn and new East River bridges, the improvement of the New York Central's Park Avenue tunnel, the proposed new Pennsylvania R. R. tunnel bridge connecting Jersey City and New York under the Hudson River and the Long Island R. R. tunnel connecting Long Island City and New York under the East River. To the student of municipal history and development, the construction of this great underground system in the Metropolis is an attempt to solve one of the many vital problems arising from the concentration of growth in the great cities of our country. In the case of New York City it is a problem of peculiar difficulty owing to the narrow confines of Manhattan Island, to the fact, that in its geological structure the Island is practically a back-bone of rock, and to the necessity that a vast number of its inhabitants must live from five to twenty-five miles away from the centres of business and yet be transported back and forth rapidly every day.

A complete and comprehensive official Report was published by the Board of Rapid Transit Railroad Commissioners during the past summer, covering the work done on the Subway from March, 1900, to December 31, 1901. This report contains much valuable and interesting detail information as well as many views of different parts of the work and a set of reduced contract drawings and other detail sketches.

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EDITORIALS.

WITH this issue the HARVARD ENGINEERING JOURNAL begins its second collegiate year. The success of the magazine last year has imbued the present Board of Editors with the spirit of still greater effort for further success. It is sincerely hoped that the graduates will give all the encouragement in their power to this worthy enterprise, for it cannot but be an inspiration to the undergraduates to read of the many interesting problems which former students of their own school, as well as of other institutions, have solved. That this inspiration may be always before us, the graduates should give us the benefit of their experiences in active practice. Particularly is it hoped that the older graduates write for the magazine, for thus alone can the paper reach the high standing that a periodical published at the University should have.

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We take great pleasure in announcing the election of John Prince Hazen Perry, '03, as a regular editor from the Department of Civil Engineering, *vice* Howard Edward Huntington resigned.

The paper by E. M. Blake, '99, appearing elsewhere in this number, will be of especial interest to us all from the number of Harvard men on the work. Among them are, George S. Rice, '71, Deputy Chief Engineer; Charles J. Tilden, '96, Inspector of Steel, and Mr. Turner, Assistant Engineer. There were also the following Assistant Engineers January 1, 1902: William Hauck, '96; William T. Stevenson, '97; Edmund M. Blake, '99; Michael H. Ryan, '99; Tyrell B. Shertzer, 1900; Frederick Wilcock, 1900; James P. Locke, 1900; and Henry J. Alexander, 1900.

During the winter, the Pen and Brush Club proposes to hold a series of competitions in simple design work, open to all members of the University. The enterprise marks a new departure, and one which, if successful, will be productive of much good.

It is hoped that this active competition will afford the Architectural students an opportunity of conceiving and completing, unaided by continual criticism, designs out of the ordinary classroom type. Under the constant supervision generally exercised, a man soon fails to take the initiative in such work. Consequently, when he enters active practice, he finds himself unable to master a mass of small but important details.

The benefit the outsiders will receive comes from the careful criticism their work will undergo. It is hoped that many will avail themselves of this privilege, and thus perhaps become more seriously interested in the work of the school. The subjects are to be of a simple nature, and a premium will be put on good taste rather than on technical skill.

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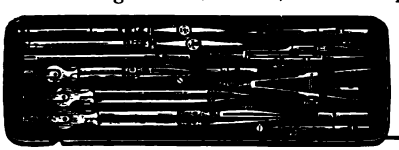
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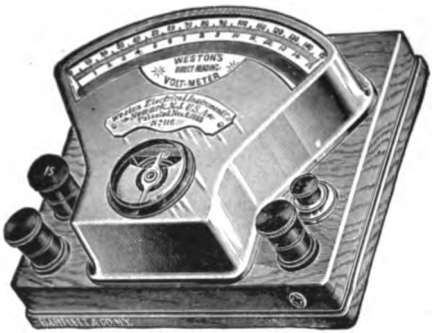
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AT HARVARD UNIVERSITY

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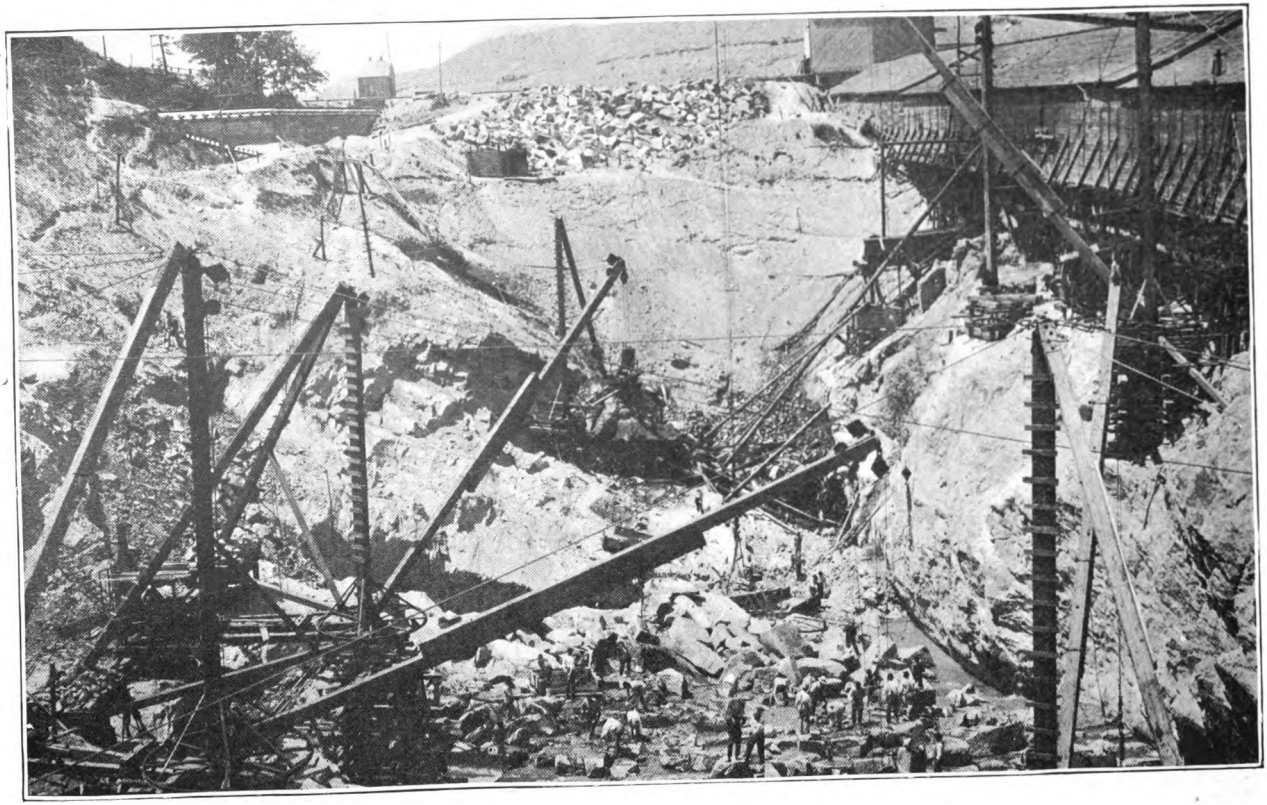
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WACHUSETT DAM.

Progress on Masonry. Small flume in upper left-hand corner.

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VOL. I **JANUARY, 1903** **NO. 4**

THE WACHUSETT DAM.

CHESTER WASON SMITH.

(From a lecture before the Civil Engineering Club, Nov. 11, 1902.)

THE Wachusett Dam, of the Metropolitan Water System, is situated on the south branch of the Nashua River, in the town of Clinton, Mass., and about a mile from the centre of the town.

In 1893 the State Board of Health, under an act of the legislature of that year, started investigations regarding a water supply for Boston and its suburbs within a radius of 10 miles of the State House.

In the report upon these investigations, made to the legislature of 1895, the scheme recommended was to build this dam, utilizing about 118 sq. miles of watershed; and forming a reservoir 8½ miles long, covering 4200 acres to an average depth of 46 feet, and containing 63,068,000 gallons of water.

An essential feature of the investigation, was to determine the feasibility, and approximate location and cost of the dam; and for this purpose topographical surveys of the site and vicinity were made, also wash drill borings to determine the depth to rock.

The legislature of 1895 passed an act establishing the Metropolitan Water Board, for the purpose of providing a water

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supply substantially in accordance with the plans proposed by the State Board of Health.

The Board was appointed and organized in July of that year, and very soon afterward its engineers began further investigations necessary for the design and construction of the dam.

More detailed surveys, many more wash drill borings, and some diamond drill borings were made; furnishing the data from which the dam and appurtenances, as well as the necessary temporary and protective works, were located and designed.

Wash drill borings are made by driving a $2\frac{1}{2}$ inch casing pipe into the ground; inside of, and accompanying the $2\frac{1}{2}$ inch pipe is a jet of water from a 1 inch pipe fitted on its lower end with a cutting point. The material encountered is washed to the surface by the escaping water between the two pipes.

The $2\frac{1}{2}$ inch casing, as well as the 1 inch drill pipe, are used in lengths of about 6 feet, coupled on at the top as driven. Above the casing, which is driven, is one length carrying the driving apparatus; on its lower end, and acting also as a coupling to the lengths being driven, is the drive head, receiving blows from a 100 lb. or 200 lb. hammer. The hammer is cylindrical, with a hole through the centre for the pipe, upon which it slides up and down. On the upper end of the pipe carrying the drive head and hammer, is a yoke with two pulleys, over which pass two ropes from opposite sides of the hammer, by means of which two men raise the hammer and let it drop.

From 6 to 10 feet above ground, on planks supported by two wooden horses, are two men, who, by means of a cross handle on top, raise and drop the one inch pipe carrying the drill point and the jet of water; thus breaking up and loosening the material encountered. A hose, attached just below the cross handle furnishes the water. The escaping water, carrying the material encountered, comes out at a spout in the side of the drive head, and is caught in a tub.

With some allowances, the material which settles in the tub is a sample of the material encountered by the boring at the time; obviously pebbles larger than the space between the pipes cannot be washed up, and in some kinds of material the sample does not do justice to the very fine portion of it.

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In addition to the sample there are other indications of the nature of the material; principal among which is the amount of water escaping from the spout, as compared with the amount furnished to the jet; in coarse porous material all the water is often lost unless the casing is kept driven several inches in advance of the drill pipe; on the other hand, in fine impervious material, the drill pipe can be driven far in advance of the casing; — thus at some borings in connection with the North Dike, on the same reservoir, the drill rod was sent down 150 feet below the casing, and practically all of the water recovered through the spout. In connection, is also noted the depth to the ground water level.

For the diamond drill borings; casings which had been driven to rock in the above manner, were left in, the diamond drill substituted for the wash drill rod, and the boring into the rock, made as a continuation of the boring to the rock. In all nearly 1000 wash drill borings and about 40 diamond drill borings, were made; covering the entire length of the dam, and for about 300 feet up and down the river, also covering the site of the waste channel.

After a careful study by Prof. W. O. Crosby, geologist of the Board, of the thousands of wash boring samples, and of the diamond drill cores, aided by the notes accompanying each boring; sections of the gorge were drawn showing the nature of the material to be encountered, and the depth to the surface of the rock. The eastern slope of the gorge is of boulder till for a depth of 25 to 45 feet, overlaying schist rock; the western slope is rather more abrupt, of sand and gravel overlaying granite. At the contact of the two rocks, underneath the original river channel, the schist becomes carbonaceous and soft; and the granite rises 20 to 50 feet as an overhanging cliff. The gorge is filled to a depth of 60 feet with sand and gravel below the river channel, and the lower portion of this sand and gravel contained many boulders, some quite large, the largest containing about 620 cu. yds.

The river furnished power for the Lancaster Mills, and its level was raised about 20 feet, or to eleva. 288.6 above low

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tide, by the Lancaster Mills dam about 3000 feet downstream. In June, 1897, the Lancaster Mills dam was torn down, and work begun on a temporary dam and flumes at the site of the Wachusett Dam.

The temporary dam is 280 feet upstream from the upper face of the permanent dam and is an earth embankment with a line of sheet piling in the centre. The large flume on the west side of the valley, designed to carry the river past the excavation for the permanent dam, is 40 feet wide, 16 feet high at the upper end and 13 at the lower; 200 feet in length of this large flume was built in 1897. A 24″ pipe was laid along the west side of the bottom of the valley, from the temporary dam to the Lancaster Mills, in order to furnish them with water, for purposes other than power, at an elevation approximately that of their former mill-pond.

On the east side of the valley is the small flume, about $7\frac{1}{2} \times 7\frac{1}{2}$ feet in section, to carry water to the Wachusett Tunnel and Aqueduct and thence to Boston; thus utilizing a portion of the supply several years before the completion of the permanent works.

The Wachusett Tunnel and Aqueduct, with a capacity of 300,000,000 gallons in 24 hours, for conveying the water to the existing Sudbury system, and thence through the Sudbury Aqueduct to the Chestnut Hill Reservoir, had been begun in 1896; and in March, 1898, it was ready for, and first received water from, the Nashua River.

Nothing further was done till 1899, when a contract was let for some preliminary excavation and masonry, necessary in order that the large flume might be extended to a point well below the excavation for the permanent dam. This contract contemplated the excavation of the earth, and sufficient rock to insure a sound foundation, also the building of the rubble masonry, under the large flume where crossed by the main dam. It was found necessary to excavate more rock than had been anticipated and by the time this was satisfactorily finished, it was too late to put in masonry; but the large flume was extended to a total length of 700 feet.

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While this work was in progress, provision was made for carrying whatever water should be let into the large flume, down a channel on the east side of the bottom of the valley. For this purpose the lower end of the existing portion of the large flume was closed by a bulkhead, an opening made midway in the east side, and a levee of compacted earth constructed between the channel and the excavation. This channel was not used, however, as the season was a dry one, and the small flume carried the entire flow of the river to Boston. The large flume is built with 8-inch x 8-inch spruce sills 2 feet apart on centres, 6-inch x 16-inch hard pine posts on each sill, a $1\frac{1}{4}$-inch tie rod across the bottom and a $\frac{3}{4}$-inch tie rod across the top, at each post; sides and floor of 3-inch splined and grooved plank spruce for the floor and pine for the sides; the whole covered with a roof and outside boarding to protect it from the weather. The flume for a portion of its length was laid directly on the ground, and at these places anchorages, made of planks about 4 feet long, having triangular feet attached to their lower ends, were spiked to the sills and the filling thoroughly rammed around them. Other portions of the flume were supported on piles, and that part over the rock foundation by posts resting on the rock; the sills being securely fish plated to the posts and piles. The posts were secured to the rock by bolts which had been tested by a pull of several tons. The grade of the flume was one in one thousand.

Thirty feet below the upper end of the flume, and on the line of the sheet piling in the upper temporary dam, are the gates to control the flow of the water. Five 15-inch I-beams, dividing the 40 feet of width into 6 sections, were set into cast iron plates, secured to the floor of the flume; grooves bolted to the I-beams carry stop planks. At the top, the I-beams are pin connected in such a manner that they, as well as the stop planks, can be removed in case of flood, thus giving 40 feet clear waterway.

The flume was designed to carry a flow of about 9000 cu. ft. per second, and during a freshet which occurred Feb. 13, 1900, the maximum discharge was 9050 cu. ft. per second, corresponding to 2.83 watershed inches per 24 hours. The flood was

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caused by a rainfall of 3.18 inches during 37 hours, coming on ground which was frozen and covered with ice from a previous rain. For a short time, while the flood was at its height, the flume was so full that the water would hit the bottom chord of the roof trusses at the lower end of the flume, thus checking the velocity of the surface water and forming a wave, which traveled up the flume considerably faster than a walk. Accompanying the wave the flume would overflow at the eaves, and five or six of these waves would be in progress up the flume at the same time, dying out in turn as they reached the higher part of the flume. At times during the freshet the striking and unexpected condition was presented of water running uphill in the flume, thus; while during portions of the time the loss of head at the entrance was about 4 feet, as expected; at other times it was more, reaching as much as 13 feet. Consequent upon this loss of head, the water in the upper part of the flume was given a high velocity, and in its progress through the flume it lost velocity and gained in section, to the extent that the water surface at the outlet was 3½ feet higher than in the upper half of the flume. At this time the lower temporary dam had not been built, and the water backed up outside as far as the upper temporary dam, and of course to the elevation of the water at the outlet, thus floating the flume for a considerable part of its length. The height to which the flume was thus raised was afterward demonstrated to have been, in places, at least 18 inches. This floating caused the failure of the hold downs, particularly the fastenings of the posts to the rock, and the anchorage pieces bedded in the ground; the fastenings to the piles seemed to have held much better. On March 2, 1900, during a second freshet, caused by a rainfall of about the same amount, coming in 34 hours, the maximum flow through the flume was 7840 cu. ft. per second. During the early part of the summer of 1900, repairs were made to the flume, principally to bring it to its grade, which had been somewhat deranged; otherwise the flume was very slightly damaged.

At this time, while the location and main features of the dam had been decided upon, some questions of detail made it advis-

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able to delay letting the contract; and as there was considerable excavation which it was desirable to have finished. Beginning July 9, 1901, a force employed directly by the Board was set at work excavating. At first, and as far as the conditions would allow, this excavation was made by teams; later, beginning Sept. 24, the method employed was a cable incline on a 20% grade, with cars hauled up by a hoisting engine, and from the top of the incline hauled by horses to the dumping ground. This was continued until the middle of October, when the contractors took over the plant and operated it in the same manner. Altogether about 43,600 cu. yds. were excavated by day labor. A portion of the excavated material was used to construct the lower temporary dam.

The contract for the main dam and appurtenances, with the exception of some superstructures, was let on Oct. 1, 1900, to McArthur Bros. Co., of Chicago, the representatives of the firm in charge of the work being Winston & Co. and Locher. The amount of the contract, based upon the engineers' preliminary estimate of the quantities, was $1,603,635. The estimated quantities of the principal items of work to be done, are as follows:

	Cu. yds.
Earth Excavation,	267,300
Rock Excavation,	100,000
Rubble Stone Masonry,	265,000
Ashlar Masonry,	10,300
Dimension Stone Masonry,	2,900
Brick Masonry,	1,300
Concrete Masonry,	8,300
Slope Paving,	2,700
Broken Stone,	2,300

The prices for earth excavation range from 25 c. to $1.00 per yard, average price 46 c. For rock excavation, 90 c. to 95 c. for the schist rock and $1.20 for the granite; for excavating rock by barring and wedging, in such manner as not to shatter

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adjacent rock not excavated, $2.00 per yard for schist and $2.50 for granite.

For rubble stone masonry the price was $3.80 to $4.80 according to kind and amount of cement in the mortar; with an additional price of 15 c. to 20 c. per yard for laying the stones, in portions of the dam, with beds inclined so as to be at right angles to the lines of pressure; Ashlar Masonry $12.00 to $13.50, dimension stone masonry $16.50 to $20.00, brick masonry $12.00 to $15.00, concrete masonry $3.75 to $6.50 according to kind and amount of cement.

Eleven bids were received for the work; omitting the highest, in which was a clerical error, the amounts ranged from $1,603,635 to $2,002,450.

The plans provide for a masonry dam, the main part of which is 850 feet long, to be carried 20 feet above full reservoir level, or to elevation 415, and composed entirely of rubble masonry except for a thin facing of Ashlar Masonry above Elevation 299, which is one foot below the restored earth surface. At the western end of this main section is a circular bastion, from which the waste weir extends upstream at an angle with the rest of the dam.

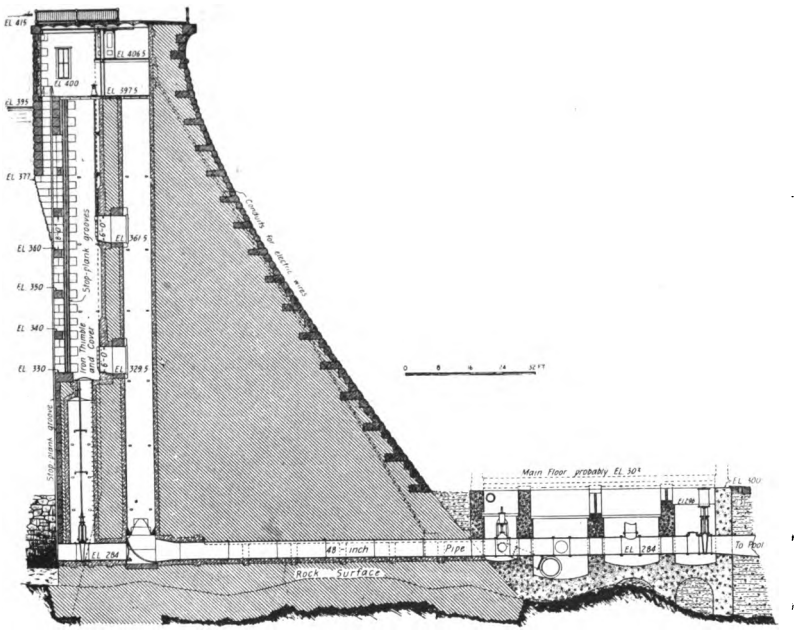
The waste weir, with its top at elevation 395, is about 450 feet long, and with a depth of 5 feet over the crest will discharge in 24 hours a quantity of water equal to 4.9 inches in depth over the entire watershed. One hundred feet in length of the waste weir next to the bastion is maintained at elevation 395 by means of stop planks, the masonry being 3 feet lower. Provision is made for the stop planks to elevation 398 along the entire length of the weir, also for a foot bridge, supported on iron standards, to give access to the stop planks. The bastion will contain a room for the storage of stop planks.

The waste water will flow through a channel, principally in rock, and following a natural gorge, and enter the river at a point about 700 feet below the dam.

At the eastern end of the main section is a semicircular abutment, and from this, extending easterly about 95 feet to the end, the dam will be a core wall founded on rock.

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Four lines of 48″ pipes are laid through the dam at elevation 284, and at their inlet starts the upper gate chamber containing two walls on each pipe line. (See accompanying cross section of



SECTION THROUGH GATE-CHAMBER.

Dam.) As a temporary arrangement for controlling the water until such time as the water shall reach elevation 330, a valve is placed in each pipe line, in the upstream wall. On the completion of the work, the upstream wells will be sealed up at elevation 330, and the water taken through six ports, each 8 feet high by 2½ feet wide, in each of the upstream wells; thence passing to the downstream wells through two 6 feet by 2½ feet gates, at the bottom of the downstream wells being deflected into the 48 inch pipes. The 48 inch pipes passing through the dam enter the lower gate chamber and power house, which is

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divided across the line of the pipes, into 4 wells, all of concrete construction.

The first and fourth wells contain valves, operated by hydraulic pressure, for regulating the flow of the water to the Wachusett Tunnel and Aqueduct, also whatever water is wasted other than that wasted over the waste weir. The two middle wells, from which the water flows to the tunnel, will eventually contain turbines for developing the power from one hundred million gallons daily, falling about 100 feet. The details of this feature of the plan have not as yet been worked out, neither has the superstructure.

The four lines of pipe, immediately after passing through the power house, increase in diameter from 48 to 96 inches, and enter concrete conduits, which, in a distance of about 20 feet, still further increase in section. This enlargement of section, from 48 inches, being made in order to reduce the velocity of discharge into the river below.

Turning an angle and continuing for about 150 feet the conduits terminate under an inner pool, into which they discharge through openings in their roofs, so proportioned that the velocity of discharge will be about 4 feet per second.

The inner pool, 55 feet in diameter, discharges over a low coping, by which it is surrounded, into an outer pool 150 feet in diameter, which in turn discharges over a spillway 110 feet long into the river channel.

Roadways and paths will be constructed, and considerable grading and other work done, with a view to the effect of the whole as a feature of the landscape.

The Contractor's plant is very complete, and admirably adapted for the rapid and economical prosecution of the work. For handling the excavation and masonry two Lidgerwood cableways were erected, having a span of 1150 feet between head blocks; and with main cables 2¼ inches in diameter, capable of handling weight up to about 8 tons. The head towers, at the east end of the dam, are 60 feet high, and the tail towers 90 feet high; all are mounted on wheels on a 7-rail track, and can be moved up and down stream about 500 feet across the work.

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The quarry is distant about 1½ miles, on land owned by the state, and a standard gauge railroad was built between it and the dam. On the line of the railroad is a pile trestle, about 800 feet long, with a maximum height of 32 feet, for the purpose of crossing over Boylston Street and the Mass. Cen. Div. of the Boston & Maine R. R. A spur track connects with the Boston & Maine R. R., in order that cement and other supplies may be brought directly to the dam without expensive handling and hauling.

About 3300 feet additional of railroad was afterward built as a switch back, climbing the hill at the quarry in order to give access to a higher working level. At the side of the Boston & Maine R. R. and between the dam and the quarry a central power plant was erected, consisting of two cross compound Rand air compressors, operated by two compound, condensing Corliss engines rated at 500 h. p. each; furnished with steam by two water tube boilers.

To supply water for cooling and condensing, a 3-inch main was laid 3550 feet to a pond at a sufficient elevation to deliver the water to the intercoolers of the compressors. A wrought iron air main 8 inches in diameter leads from the compressor to the dam, and one 6 inches in diameter to the quarry; and, with a station pressure of 90 to 95 lbs. per sq. in. has supplied all the power required on the contract, except for the locomotive on the railroad, since the middle of April, 1901.

Alongside the tracks at the dam, and a short distance from the head towers, are two cement sheds with a combined capacity of 4500 barrels.

The cement is wheeled out on to a mixing platform between the sheds, and with the sand, is dumped into a 4 ft. cubical mixer underneath. On the mixing platform are several barrels in which to gauge the amount of water per batch, the water passing by a pipe and entering at the axis of the mixer. The mixer which turns at the rate of 11 turns per minute, is given 5 turns to mix the sand and cement, before water is turned in, after wetting it is given 20 turns; the mortar is then dumped into a skip on a small car underneath, hauled by a mule to a point under either cableway, and transferred by cableway to the masonry.

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Across the track, and up the hill from the cement sheds, is a sand bin with a capacity of 370 cu. yds. to which the sand is hauled by teams from the pit, distant about ½ mile. Through chutes in the bottom of the bin, the sand falls into cars holding about one cubic yard: the cars run out on a track, crossing over the quarry railroad on a trestle, to a point over the mixing platform, and there are dumped into the hopper which receives the cement.

A pump at the edge of the river, just above the upper temporary dam, pumps water to a tank beside the quarry track, at the south end of the cement sheds. This tank feeds the locomotive, supplies the water for mortar mixing, also for washing the rock foundation and the stone used in the masonry.

At the sand pit the material is hauled by wheel scrapers to a belt elevator and raised to a rotary screen, where the sand and gravel are separated, dropping into separate bins. From these bins the sand and gravel falls through chutes to teams underneath, which haul it to the bin by the mixer. The gravel from this pit furnishes all of the stone used in the concrete.

To haul the stone from the quarry to the dam there are employed about 30 flat cars, holding 4 skips each at a load, and a 60 ton, ten wheel locomotive. The skips, or scale boxes, are filled at the quarry and hauled to a point underneath the cableways, near the head towers; there the skips and contents are picked up from the cars and set down on the wall within reach of the derricks. An average skipload of large stone contains about 2.3 cu. yds.; and of spalls about 1.9 cu. yds., solid measure.

The directions to the engineer as to the movements of the cableway are all given by electric signals, by a signalman, who occupies a perch in a prominent position whence he can overlook the entire work, and in turn see signals given him by tagmen who hook and unhook the skips.

On the masonry, whistles are blown, as signals to the men mixing mortar and passing down the mortar and stone; the number of blows indicating what is required on the work, large or small stone, or which of the various kinds of mortar.

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The derricks, of which the maximum number in use has been 10 at the dam and 9 at the quarry, are all equipped with bull-wheels so that they can be turned by the engine; thus doing away with tagmen and otherwise facilitating the work. The derricks at the quarry are all supported by guys; those at the dam, at first, while at work on the lower portions of the masonry, were rigged with two or three guys and a stiff leg; the guys sustaining the weights while the derrick was in use, and the stiff leg bracing the mast against the guys; all leading back to dead-men on the slopes of the excavation, thus doing away with guys across the masonry, which would have seriously interfered with the working of the cableways.

As the masonry climbed higher, rendering impossible the stiff leg to the ground, rigid frames were constructed in the shape of three right angled triangles; one setting horizontally carries the engine, and at its right angle stands the mast, forming the perpendicular of the other two triangles, no guys being used. These structures are picked up entire and transferred by the cableways whenever there is occasion to move them.

An office, repair shop, store houses, powder houses, boarding and lodging houses, have been erected at various points between the dam and the quarry.

The approximate cost of the plant was as follows:

Power plant, including foundations and buildings	$65000
Two cableways erected, including grading for tracks	37000
12000 feet of railroad (including trestle) and rolling stock	45000
22 derricks, including guys, bull-wheels, sheaves, and wire rope	27000
22 hoisting engines	26000
26 Rand air drills	7800
19 Pumps, plunger and centrifugal, all sizes	7200
One 4 ft. cubical mortar mixer, and engine, erected	1200
Sand screen	1200
Stone dressing machine	500
Five boilers; and several engines other than hoisting engines,	7500
80 Stone skips	3200
About a dozen dump cars, various sizes	2500
Wagons, scrapers, mules, harnesses, small tools, and miscellaneous	13000
Office, store houses, repair shop, boarding houses, etc.	15000
Total	259100

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The contractors worked on the excavation with the cable incline till Nov. 2, 1902, when work was suspended till such time as they should be able to handle it with the cableways, as being much better fitted for the deeper excavation. One cableway was ready for operation Dec. 24, 1900, and the other on Jan. 26, 1901, using steam at first as the compressor was not completed; and work on the excavation was pushed, till on June 5, 1901, it was so far advanced that the laying of masonry was begun. A night shift was organized and started Feb. 28, 1901, arc lights being installed for that purpose, and since the cableways have been occupied daytimes on the masonry, nearly all of the excavation has been done at night. As the excavation was carried downward it was found that the indications from the preliminary borings, as to character of material and location of the rock, were sustained with remarkable accuracy. From the number of borings stopping on boulders at about elevation 235, it was supposed that the material below that elevation contained many boulders, and it did as above noted; also the overhanging granite cliff, in character and extent, agreed closely with the sections constructed from the borings. Enough of the surface rock, which was more or less disintegrated and seamy, was removed to reach a sound foundation.

On approaching what promised to be a satisfactory foundation, blasting was prohibited, as tending to open up seams in the rock, and all further excavation made by barring and wedging. The average depth of rock excavated by blasting was 13 feet, and by barring and wedging 1.5 feet; also much of the overing granite cliff was removed. As an additional assurance that the excavation was carried below all seams, and as furnishing a bond between the masonry and the rock, a cut off trench 20 feet wide and with an average depth of 14 feet below the general level of the foundation was excavated near the upstream face of the dam and filled with masonry. On the side lines of this trench were drilled 3-inch holes 6 inches apart, so that when the rock in the trench was blasted it would break on the lines thus weakened leaving the sides of the trench perpendicular and unshattered. For blasting, these holes were not loaded, others

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being drilled toward the centre of the trench. After the foundation had been reached, the diamond drill holes were found and filled with grout, the surface to be built on carefully cleaned and given a wash of the same. The lowest point reached in the excavation was elevation 187. in the cut off trench at the contact of the schist and granite. The general level of the foundation at the bottom of the gorge was 207.

The quantity of water pumped from the pit per 24 hours varied from about one million gallons soon after the excavation was started, to a maximum of nearly four million gallons pumped against about 70 ft. head, when the excavation was at the lowest point. For a portion of the time, before the quantity and the head had reached the maximum, it was handled by several centrifugal pumps, sometimes dividing the total head by pumping into a tank at an intermediate elevation, and from that into the large flume, into which nearly all the water was pumped. For the maximum quantity and head, two 12-inch duplex Worthington pumps were used, one at the upstream side of the pit and one at the downstream. In connection with these, several auxiliary pumps, centrifugal and plunger, were maintained, and employed portions of the tim

The slopes of the excavation, $1\frac{1}{2}$ horizontal to 1 vertical, were not seriously disturbed at any time. On several occasions there were small slides in the upstream slope, which was almost entirely sand, but the stability of the slope was maintained without much difficulty by putting on rock.

In the cut off trench, and for a thickness of 4 feet all over the foundation, the rubble is laid in 2–1 Portland cement mortar; above this, to a plane cutting the downstream face of the dam at elevation 260 and the upstream face at eleva. 187.84, the mortar is $2\frac{1}{2}$–1 Portland. Above this plane, and including the bulk of the rubble, 2–1 natural cement mortar is used; except in freezing weather, when 3–1 Portland cement mortar is substituted as being much less liable to be injured by frost. The stone is a Muscovite granite, weighing 165 lbs. per cu. ft. of a good quality for working, and with a crushing strength of 165,000 to 170,000 lbs. per sq. ft. The quarry, which is not

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stratified, was worked during the winter of 1901–1902, and to Feb. 5, 1902, 51,000 cu. yds. of rock had been taken out, of which quantity not quite one half was available for masonry, the remainder being largely rock necessarily wasted in opening the quarry. Each stone after being washed, is placed on a bed prepared with mortar and thin spalls, the stone being set in place as a guide to the preparation of the bed. After outlining the bed with spalls, the stone is lifted and the bed formed with mortar, the stone then replaced and thoroughly bedded by working it back and forth with crowbars, settling it in the mortar. Occasionally a stone after being bedded, is raised to test the quality of the work. The joints between large stones are filled with spalls and mortar, no grouting of joints being allowed, and care is taken to bond thoroughly, avoiding anything resembling continuous joints or layers in the masonry. On the upstream face of the dam, below elevation 299, where the ashlar begins, a joint not to exceed 1 inch in thickness for 2 inches back from the face, was required; these joints to be raked out and pointed with 1–1 Portland mortar. Against this face, and for 10 ft. in thickness, the filling is clay, rammed in 6-inch layers, or puddled.

The usual gang for a derrick is, one foreman, one hoisting engineer, 4 masons, and 5 laborers or mason helpers; the masons per derrick ranging from 3.9 to 4.5. At the beginning of the work, the amount accomplished per 10 hours was 39 cu. yds. per derrick, or about 9½ cu. yds. per mason; this amount has since increased with considerable regularity to 53 cu. yds. per derrick, or 13 cu. yds. per mason. When the masonry was started only two or three derricks could work on it, but this number was soon increased, and at the end of the season seven were in use. The largest number during 1902 has been 9, and for a portion of the season two or three of these were employed otherwise than on rubble; such as setting the 48-inch pipes through the dam, and building brick, ashlar and dimension stone masonry.

In freezing weather, as above noted, 3–1 Portland mortar is used in place of the 2–1 natural mortar. The sand for the

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mortar is heated by a coil of steam pipes in the bin; the water used in the mortar is heated; steam is used on the masonry to take the frost out of the stones, and thaw any ice that may have formed; salt is used in the mortar to the amount of 4 lbs. per barrel of cement, and all fresh work is covered with heavy canvas each night. After work closed for the season of 1901, water was allowed to rise and cover the masonry as a protection from the cold weather, and it was pumped out on the resumption of work in the spring of 1902.

During 1901 28,486 cu. yds. of rubble masonry were laid; composed of 4749 cu. yds. or 16⅔ % of spalls, 8259 cu. yds. or 29 % of mortar, and 15478 cu. yds. or 54⅓ % of large stone. To Nov. 18, 1902, a total of 88650 cu. yds. of rubble had been laid, or about ⅓ of the whole.

Following are the amounts of cement used per cubic yard of masonry, based on the work done up to November 18, 1902.

		Bbls. of cement per yd. of masonry
Rubble	With 2–1 Portland mortar	1.08
	" 2½–1 " "	0.86
	" 3–1 " "	0.72
	" 2–1 Natural "	1.00
Portland Concrete composed of 1 part cement, 2½ sand, and 4½ parts gravel.		1.41

The brands of cement used are, Giant, Portland, except a very small quantity of other brands; and Union natural.

A barrel of the Portland, which comes in 4 bags,
= 3.6 cu. ft. = 380 lbs.

A barrel of the natural comes in 3 bags,
= 3.6 cu. ft. = 300 lbs.

At the mortar mixer they begin work about ¾ of an hour before the mortar is required, in order that they may have each gang supplied with a batch in readiness to start work. A few of the batches are 1 cu. yd. batches; usually however a double batch is sent down in a skip.

The elapsed time between mixing and using the mortar, as

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observed on an average day in Oct., 1901, was as follows; 8 double batches were used in an average of 2 hrs. 12 min.; 29 double batches in an average of 1 hr. 41 min.; and 10 single batches in an average of 1 hr. 14 min.; counted from wetting of the first batch in the double batches, till the last of it was used. Owing to a slight change since made in the method of mixing, the time is now in all cases less than two hours. There was an average of 6 minutes between wetting of the two batches in a double batch.

It will be noticed that the time elapsing between mixing and using the mortar, very much exceeds the time usually allowed; the common practice being, to specify that mortar may be rejected if not used within half an hour of the time it is mixed, or some such similar provision.

It is obvious that in mixing and delivering by the method above described, not much shorter intervals of time could be expected, or obtained, than those above noted; and during the winter of 1900–1 experiments were conducted at the Clinton office, to determine the relative strength of mortars used immediately after mixing, and mortars used at different intervals up to two hours after being wet.

While the details of these experiments are not at present available for publication, the results fully justify the method of mixing in use at the dam. To quote from the Annual Report of the Metropolitan Water and Sewerage Board dated Jan. 1, 1902, "These experiments were very extended, as they were made with mortar mixed with different grades of sand, with Portland and natural cement, with slow-setting and quick-setting cement, and with mortar that was worked continuously from the time of mixing until it was put into the molds, and also with mortar which was not worked after it was mixed until just before it was put into the molds. The briquettes were broken at the end of fourteen days, twenty-eight days, and three months after mixing."

"It was found that when the cements, both Portland and natural, were so manufactured as to take the initial set slowly, the strength of the mortar was not diminished by a delay of

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two hours in putting it into the molds; and when the mortar was worked continuously to the time of filling the molds, there was an increase in strength occasioned by the delay. When the cements were so manufactured as to take the initial set quickly, the results obtained with the Portland cement were not materially different from those obtained with the slow setting cement except that when the mortar was not worked there was a slight loss of strength in the briquettes molded at the end of one and a half and two hours, and at no time was there much gain in strength occasioned by delay in filling the molds. The results obtained with the quick-setting natural cement were less favorable; as the briquettes broken at the end of fourteen days showed a great loss of strength when there was much delay in molding the briquettes. At the end of three months, however, the briquettes made with mortar which had been worked continuously from the time of mixing showed slightly greater strength than that put into the molds immediately, and the loss of strength of the mortar not worked was not very marked except for the one and a half and two hour periods."

Experiments were also conducted to ascertain the relative strength and permeability of mortars composed of the Portland and natural cements to be used in the dam, mixed with sand of varying degrees of coarseness. It was found that with proportions not exceeding 3 of sand to 1 of cement, a fairly coarse sand gives better results as to both of those qualities. All of the experiments above described were made with perfectly dry sand.

Following are some determinations of the bulk of various kinds of mortar, using pit sand containing six and a half per cent of moisture.

With six to seven per cent of moisture, which is the average amount in the sand as used on the work, the bulk of the sand is increased about fifteen per cent over that of perfectly dry sand.

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	cubic centimeters of ingredients.		cubic centimeters of mortar.
Union 2–1	1000 Pit sand 500 Cement 355 Water	=	1100
Giant 1–1	1000 Pit sand 1000 Cement 500 Water	=	1570
Giant 2–1	1000 Pit sand 500 Cement 265 Water	=	1100
Giant 2½–1	1000 Pit sand 400 Cement 235 Water	=	1010
Giant 3–1	1000 Pit sand 333 Cement 220 Water	=	995
Giant 4–1	1000 Pit sand 250 Cement 215 Water	=	965

A mechanical analysis is made of the sand each day, a sample being taken at the screen for that purpose. After being dried it is passed through three sieves, of eight, thirty and one hundred meshes to the inch respectively. The aim is to get a sand of which 50% or over will stay upon the first two sieves; so for this has been accomplished without difficulty with sand from the pit in use, occasionally mixing sand from different parts of the pit for that purpose.

In connection with the method of measuring the sand, by filling a certain sized car from a chute, as elsewhere described, the specifications say that the sand shall not be compacted more than by throwing into a box or barrel in the usual manner (i. e. with a shovel.) The contractor made the claim that by the chute he was not getting as much sand as the specifications permitted, and several experiments were made to ascertain if such was the case, and if so, how much loss there was. As the result of several experiments made under varying conditions, the claim was substantiated to the extent of 0.9 cu. ft. in a car measuring 25.8 cu. ft. and that allowance was made.

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Following is the record of the performance of the cableways for one day.

Cable # 1	86 trips	= 627.	min.	Delivered on the wall, 68 skips of large stone, 23 skips of spalls, 26 double and 23 single batches of mortar; which is about sufficient in quantity and proportions for 283 cu. yds. of rubble masonry. Since then as high as 450 yds. have been laid per day, with a proportionate increase in number of trips. At the time of this record the loads were run out about 400 feet, and lowered about 120 ft. to the masonry.
	Average trip	= 7.29	"	
	10 shortest trips	= 36.	"	
	10 shortest consecutive trips	= 52.	"	
Cable # 2	59 trips	= 581.	"	
	Average trip	= 9.85	"	
	10 Shortest trips	= 49.	"	
	10 Shortest consecutive trips	= 87.	"	

The concrete, principally Portland 1–2½–4½, in the foundations and wells of the power house and n the conduits leading to the pool, of which 5100 cu. yds. have been built, all during the season of 1902, was built at night. This was done in order that the cubical mixer and a cableway, which during the daytime are at work on rubble masonry, might be employed on the concrete. A portion of the sand bin was reserved for the gravel; a car, which during the day carries sand for the mortar, is used at night for the gravel, and a smaller car for the sand. The concrete is mixed rather wet and sent down in the same manner as the mortar; sometimes being dumped in place and spread with shovels; sometimes cast from the skip or a dumping platform, and sometimes shoveled into wheelbarrows, wheeled over runways and dumped, according to the location of the work. Besides ramming thoroughly, considerable care was used to insure a smooth surface, which was done by working spades up and down along the lagging.

Owing to the shapes which it was desired to produce, as well as to the number of pipes and special castings which were built into the concrete, the forms were often quite complicated, requiring a force of about 5 carpenters practically all the time to erect them. The forms for most of the work were removed 48 hrs. after placing the concrete, except arch forms which were left in for a longer time.

On some of the higher walls it was difficult to brace the forms

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from the outside sufficiently to insure against any distortion or bulging from the pressure of the wet concrete, and at such places the sides were tied together with tie rods of ½ inch iron, the rods being built into the wall and the ends cut off after the concrete had set. Immediately before placing any concrete, all surfaces, whether of lagging or old concrete, to be built against, were thoroughly washed.

Nearly six hundred tons of pipe, valves, and other iron work have been set, being handled by the cableways and derricks. Some of the pieces weighing up to 11 tons each, being slung between the two cableways working side by side; some of the operations requiring considerable delicacy and precision in the handling of the cableways.

In addition to one day, and one night, inspector at the mixer, there is one at the placing of the concrete; and, on the rubble masonry, about one for each two derricks.

For the measurement of the work, earth sections 20 ft. apart are taken; for rock excavation and masonry construction the sections are taken 10 feet apart, except at the granite cliff, where a few intermediate ones were desirable.

The chief engineer for the Metropolitan Water and Sewerage Board is Frederick P. Stearns, Mem. Am. Soc. C. E., who was also chief engineer for the State Board of Health during the preliminary investigations. The consulting engineers are Joseph P. Davis, Mem. Am. Soc. C. E., Alphonse Fteley, Mem. Am. Soc. C. E., and Hiram F. Mills.

The work has been executed under the supervision of Thomas F. Richardson, Mem. Am. Soc. C. E., who is engineer of the Dam and Aqueduct Department. The writer, who with a corps of five assistants, has had immediate charge at the dam, would acknowledge material assistance, in the preparation of this article, from the published reports of the Board; and, regarding cost of plant, from the contractors for the work.

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SCREW PROPELLERS.

EDMUND BAKER EDWARDS, A. B. '98, S. B. 1900.

(From a Lecture before the Mechanical Club, Dec. 5, 1902.)

THE first application of steam engine to the propulsion of ships involved a departure from the usual instruments of propulsion. It is very difficult to work an oar or paddle of the old type by machinery. The first and until lately the almost universal means of sending a boat through the water was the paddle wheel, and even now paddle boats are being built extensively for special service in smooth and shallow water. The screw propeller was a step which required more daring. It is supposed to have been invented by Ericsson who designed the "Monitor," though there are other claimants. At any rate the invention was at a time well within the memory of men now living.

The advantage of the propeller over the paddle wheel is due to a number of points. The first to attract attention of designers was the application of the propeller to warships. The paddle wheel was very much exposed to the enemy's shot and shell, and also interfered with the arrangements of guns, and consequently it is not surprising that the first general use of propellers was on vessels of war. It was supposed at the time of the adoption of the propeller that it would be less efficient for propulsion than the paddle wheel, and this idea was probably not given up until Froude's famous tests of the "Electo" and the "Rattler," where two vessels of about the same power and size, one fitted with paddle wheels the other with a screw propeller, were hitched stern to stern by a long hawser, and much to the surprise of the witnesses the propeller boat towed the paddle wheel craft stern first at a speed of about 2 knots against the full power of her engines. Since that time the propeller has been generally adopted for all sea going craft.

The general theory of marine propulsion is the same for any

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of the methods ordinarily used, outside of sail power. A jet of water is driven astern and the reaction drives the boat ahead. The jet propelled boat is then the simplest form in theory for us to consider.

Let V = the velocity of jet in respect to the ship.
v = velocity of the ship.

Then $V - v$ = the slip or velocity of jet in respect to still water.
$\frac{V - v}{V} \times 100$ = slip per cent.

Let A = area of the jet in sq. ft.
Assuming the weight of salt water to be 64 lbs. per. cu. ft.
Wt. of water per sec. $= A \times V \times 64$.

$$\text{Momentum} = \frac{A \times V \times 64}{32}(V - v) \qquad \text{If } g = 32.$$

$$= 2AV(V - v).$$

$$\text{Effective work} = 2AV(V - v)v \qquad (1)$$

$$\text{Kinetic Energy lost in wake} = \tfrac{1}{2}M(V - v)^2.$$

$$= \tfrac{1}{2}\frac{AV \times 64}{32}(V - v)^2.$$

$$= AV(V - v)^2. \qquad (2)$$

Total Energy (Sum of (1) and (2))

$$= AV(V^2 - v^2) \qquad (3)$$

Efficiency = ((1) divided by (3))

$$= \frac{2AV(V - v)v}{AV(V^2 - v^2)}$$

$$= \frac{2V}{V + v}$$

Assume slip $= 0$.

$$V = v$$

$$E = \frac{2v}{2v} = 1.$$

Assume slip $= 50\%$.

$$V = 2v.$$

$$E = \frac{2v}{3v} = \tfrac{2}{3}.$$

It will be noticed that the efficiency neglecting friction does not fall off nearly so fast as the slip increases. This is a matter of great importance when we come to consider the action of a

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material propeller. Now let us consider a jet in practice. The jet must be impelled, of course, by some sort of a pump, probably centrifugal, in the vessel itself and this with the piping involved necessitates a great deal of friction. Then too either the jet must be very small in which case the velocity is so high and the friction so great that the efficiency is exceedingly low or the pipes are so large as to take up a great part of the room. Let us suppose a propeller working in the pipe instead of the centrifugal pump. Then we may move the propeller aft till it is entirely outside the stern, the tube being prolonged around it and we have not essentially changed our conditions. Now remove the tube and the efficiency of the propeller is in no wise decreased but the available room in the vessel is increased, and we now are at liberty to enlarge our propeller to such dimensions as will give good efficiency.

As we have seen a propeller in theory becomes more efficient the larger the area and the smaller the slip but we have neglected two important items. The first is due to the resistance of the blades due to their thickness, this is however not so great as that due to surface friction. When we consider that the friction of a square foot of smooth metal moving at a ten knot speed is not less than one pound, and that the tips of a propeller revolving at high speed travel as fast as sixty miles an hour and that the resistance varies approximately as the square of the speed, it is easy to see that a very large propeller with both increased area and increased pitch speed may use up much more work in friction than there is saved by the decreased slip. This was not very well realized in the early history of propellers and it was first forced to the attention of practical men through accident. A four bladed propeller had one blade accidentally broken off and the opposite blade was removed for balance so that the vessel might be run temporarily until it was convenient to dock her for a new wheel. To the great surprise of all concerned the vessel made considerably higher speed than before. This was by some attributed to the superiority of the two bladed propeller but the real facts of the case were demonstrated beyond dispute by Froude's tests on H. M. Ship "Iris." Since that time the

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problem has been attempted by a great many skilled experimenters, but so far the results cannot point to any thoroughly rational theory. Knowledge of propellers is entirely empirical.

Some very good work has been done by Prof. Durand of Cornell on the efficiency of propellers working in undisturbed water. The propellers were run on the forward end of a shaft set well to one side of a launch and the power transmitted through a dynamometer. It was so contrived that the thrust could be accurately measured. The speed of the launch was also taken with great care. In general it was found that a maximum efficiency occurred with about 25% slip and that this maximum was in the neighborhood of 65%. These tests were made with varying ratio of pitch to diameter and the amount of slip corresponding to a maximum efficiency varied a little, but the efficiency itself seems to be about the same for any fixed ratio between one and two, which covers almost all practical cases. It is also found from these experiments that as the slip increases beyond the point of maximum efficiency, the efficiency falls off slowly, while as the slip decreases the efficiency falls off very quickly, hence in general it is better to have the propeller a little too small than too large, unless some special condition is to be considered.

The application of the empirical knowledge we have of propellers involves knowing the necessary power to drive a ship. Here again our knowledge is altogether empirical. The resistance of ships is a combination of three principal factors namely: surface friction, wave making and eddying. The first factor varies approximately as the 1.8 power of the speed. The wave making resistance is almost negligible at very low speeds but varies very roughly as the square of the velocity, although the curve is really a more complicated one than this equation would give, falling at certain points above and at other points below the parabola. The eddy making resistance is one which is dependent on the form of the vessel and in a fine lined craft may be disregarded. The practical method of estimating resistance of a new vessel is to use one of several empirical formulae taking the constants from some vessel of as nearly as possible

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the same type. The formula most commonly used, known as the admiralty coefficient formula, is as follows:

$$I\,HP = \frac{D^{\frac{2}{3}} v^3}{A_c}$$

D = Displacement.
V = Speed in knots.

Where A_c, known as the admiralty coefficient, is for very large vessels from 250 to 300, for torpedo boats and destroyers generally in the neighborhood of 200 and for launches often drops as low as 150.

The actual value of this constant in some high speed craft is as follows

"Albatross"	Thorneycroft	218
"Porter"	Herreschoff	204

The lowest for which I have record in torpedo boats:

"Great Britain"	Thorneycroft	142

For small cruisers a few values are as follows:

"Detroit"	204
"Charleston"	220
"Philadelphia"	238
"Marblehead"	194

For the launch "John Harvard" Lawley about 130

Another formula sometimes used bases the resistance upon the area of the midship section, the formula being as follows:

$$I\,HP = \frac{A v^3}{C} \quad A = \text{area midship section.}$$

Here C is approximately 600 for very large craft.

In small fast vessels		about 400
"Porter"	Herreschoff	425
"Cushing"	Herreschoff	310

In launches it falls lower still

"John Harvard"	Lawley	300

Some values of this constant on some of the U. S. Cruisers.

"Detroit"	558
"Charleston"	686
"Philadelphia"	727
"Marblehead"	550

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There seems to be a great variation in these constants and a large amount of data is necessary if we wish to get at our results with any great accuracy. Considerable judgment and care is necessary to be used in determining the constants when vessels are to be designed which are nearly of the same type.

Having in this way determined our probable resistance we next come to the problem of designing the proper propeller. First, in regard to the diameter there are a number of formulae known, but the most reliable in the general case is as follows:

$$\text{Diam} = K\sqrt{\frac{I\,H\,P}{(P \times R)^3}} \qquad \begin{matrix} P = \text{Pitch.} \\ R = \text{Revolutions.} \end{matrix}$$

Here K is generally 20000 for large vessels of medium speed, though for cargo ships of slow speed 17000 to 18000 is the proper figure. For such high speed crafts as torpedo boats and torpedo boat destroyers 25000 is in general about the proper figure but here there is another factor which I shall take up later which may necessitate a still larger wheel to prevent cavitation.

Some figures from boats so far actually built are as follows:

"Lancer"	Normand	33000
"Dalghren"	Bath Iron Works	30000
"Forban"	Normand	30000
"Daring"	Thorneycroft	24600
"Great Britain"	Thorneycroft	22000

The figures from some of the U. S. Cruisers are as follows:

"Detroit"	22500
"Charleston"	22300
"Philadelphia"	26400
"Marblehead"	20800

A number of formulae have been suggested for determining the proper pitch, but I cannot see that any of them have any bearing on the subject. The pitch of the propeller is not a propeller problem but an engine problem. The engine is designed to develop a certain power at certain revolutions and the propeller must then work at that speed. The pitch then must be

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such that the product of pitch × revolutions shall equal the speed of the boat × the slip and it is here usual in the ordinary case to assume about 15% slip, although here again recourse to data of similar craft is necessary. There may seem to be an inconsistency in the assumption of the 15% slip when we consider Prof. Durand's experiment, but we must remember here another important consideration, the friction of the vessel in its passage through the water causes the movement of the water with the vessel. Standing near the stern of a large vessel and looking over the sides one can see very plainly that the water near the ship is moving with a speed almost as great as that of the vessel. A foot further out the speed of the water is considerably less and a few feet further is practically still. Now the propeller is working in this following wake, and this wake is generally estimated to have about 10% of the speed of the vessel. Consequently when the apparent slip is about 15% the real slip or slip relative to the water in which the propeller is working is about 25% or near the point of maximum efficiency. For slow long cargo ships where the resistance is almost entirely frictional and consequently the weight velocity high an apparent slip of 10% is correct. On the other hand for small craft, such as launches, the wake has less speed and an apparent slip of about 20% should be assumed.

The thrust of a propeller obviously varies *ceteris paribus* with the area and consequently as the square of the diameter. The thrust varies also as the square of the speed. Hence we may write

Thrust varies as $D^2 \times (R \times P)^2$ where D = Diam. P = pitch and R = r. p. m. Hence

$$\text{H. P. varies as } D^2 \times (P \times R)^3 \text{ and}$$

$$\text{H. P.} = K \times D^2 \times (R \times P)^3.$$

Where substituting a proper value for K we get the formula for size which we have already considered Here however we have assumed that we had a continuous function of the speed, whereas the thrust is a discontinuous function. Water will not flow into a propeller with any greater speed than that due to the head and with a propeller near the surface that head cannot

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exceed atmospheric pressure. Hence if the propeller be run faster and faster there comes a point when the thrust does not increase, and this we should naturally suppose would be when the thrust reached a pressure of 15 lbs. to the sq. in. As a matter of fact the attainable pressure is somewhat less. Very careful and ingenious experiments have determined the maximum attainable thrust to be about 12 lbs. to the sq. in. with the propeller near the surface; with an increase of $\frac{3}{8}$ of a lb. approximately for every foot of submersion of the tips. Now the actual thrust at each point of the blade it is impossible to determine, but if we consider, barring friction and inefficiency, that the work done by the propeller must equal the work done by the engine it is obvious that

$$\text{Thrust} = \frac{33000 \times \text{Horse Power}}{\text{Pitch} \times \text{Revolutions}}$$

We usually deal with what is called the indicated thrust which we determine by this formula. It is found from experiment that the effective thrust is about $\frac{2}{3}$ of this value. Hence we may say that the indicated thrusts cannot exceed $1\frac{1}{2}$ times 12 or 18 lbs. to the sq. in. Now in the case of very high speed vessels of enormous power, propellers determined by the formula previously given would have insufficient area, and that accounts for the high value of the constants in such vessels as the "Albatross" and "Forban." The highest indicated thrust per sq. in. of which I have record is

"Pluton"	Clydebank	16.3 lbs. per. sq. in.
"Farragut"	Union Iron Works	14.5
"Great Britain"	Thorneycroft	13.3

Another formula sometimes used in this connection is the number of cubic ft. of water handled per minute per H. P., that is the volume of a cylinder of water of the diameter of the propellers and of length equal to pitch × r. p. m. divided by the H. P. This apparently should not be less than 40 in any case.

The area of the blade in general is about 35% of the disc area for a three-bladed wheel and 40% for a propeller with four

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blades. This is sometimes exceeded in torpedo craft for the sake of getting sufficient area to prevent cavitation without undue tip friction but 50% seems to be about the limit in any case. There has been of late a new departure in that respect in the case of the turbine vessels where the revolutions are very high and the friction of the ordinary type of propeller precludes its use. This was first adopted so far as I know on the "Turbinia" where several propellers were placed in series on each shaft. On the later turbine destroyers nine propellers on three shafts are used.

It is essential that a propeller should be sufficiently thick in the blade for strength and rigidity. The calculation can be only approximate. A blade may be considered as a cantilever beam uniformly loaded with a pressure of 12 lbs. to the sq. in. as even in slow craft the point of cavitation may be sometimes reached in starting. The more general method however is to work from some successful propeller, as according to the theorem of stresses in similar bodies enunciated by Prof. James Thomson two propellers of different size, but proportional, are equally well fitted for, and equally stressed by, the same unit load. In propellers for high speed where efficiency is the first object manganese bronze or phosphor bronze are generally used, although wrought steel has been successfully used by Thorneycroft. In a cheaper grade of work cast iron is common, and though less efficient, and subject to corrosion, has one advantage for boats and vessels which are likely to work around obstructions. That advantage is brittleness. It is better to have a blade snap off clean than to throw all the strain on the shaft. The hub is usually designed in reference to the size of the shaft, and is generally fitted with a taper of $\frac{3}{4}''$ diam. per ft. length. A steel key is fitted (navy department generally requiring two) and a large nut screwed on to the end of the shaft to prevent the propeller backing off when going astern.

There is one subject in connection with propellers that has caused a great deal of discussion in the technical papers in the last twenty years, viz.: negative slip. This seems to be a paradox. How can a propeller force a vessel against considerable

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resistance through the water acting on a body of water which it also moves forward. This seems like a case of action and reaction being equal in the same direction. Of course when negative slip is found it is what we have defined as apparent slip, that is, the real slip of the propeller through the water in which it acts is less than the speed of the actual wake. The efficiency in such a case is however very low, and wherever a case has been found of negative slip and a smaller higher pitch propeller substituted, giving positive slip, the efficiency has been greatly increased, but even though this be apparent slip only, it still seems to be a paradox. Now, in every case that I have ever heard of, negative slip has been with a single screw vessel with rather full lines, so that the water coming to the propeller is rapidly converging.

Let us imagine a hollow truncated cone somewhat the shape of a megaphone, with the propeller inside, advancing through the water without friction. If the propeller be at the small end and equal in size to the hole in the small end, the speed of the water or the real slip would be the same as the apparent slip; but suppose that the propeller is at the big end, then it is obvious that relatively to the moving cone the speed of the water at the small end is higher than that at the propeller in the inverse ratio of the areas of cross section. Here then we would have a very great negative slip thoroughly accounted for. My idea is that something of the sort takes place with the actual propeller. The water coming into the propeller does not come in in parallel lines, but is converging and, due to its inertia, continuously converges aft of the propeller in much the way that water flowing through an orifice converges at the *vena contracta*. If then this contraction is sufficient, the increase in velocity at this point would clear up the paradox.

The efficiency of a propeller depends in a very marked degree upon one cause outside of a propeller itself, viz.: the shape of the stern which so should allow free and unrestricted flow to the blades. A very interesting case in point is that of a very full cargo vessel built some years since at Port Glasgow on the Clyde. This vessel was fitted with a rather small propeller

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situated very close to the full stern. With the engine going full speed astern the vessel went astern about 6 knots. With the engine running full speed ahead the vessel went astern about 4 knots. Do what they would the vessel went astern. The explanation of this is not difficult, the stern was so full that the water could not flow in freely to the forward side of the blades, consequently the water was thrown off from the tips as in a centrifugal pump and the water flowed in from aft to take its place and the vessel went backward. A propeller of larger diameter was substituted. This reached out into solid water and the vessel could be manoeuvred.

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THE HEATING AND VENTILATING SYSTEM

Robinson Hall, Harvard University

DENSMORE AND LE CLEAR, ENGINEERS.

Robinson Hall, the building for the Department of Architecture in Harvard University, is a two-story, fire-proof constructed building, designed by McKim, Mead, & White of New York. The floor plans, Figures 1 and 2, indicate the arrangement of the rooms and the uses to which they are put.

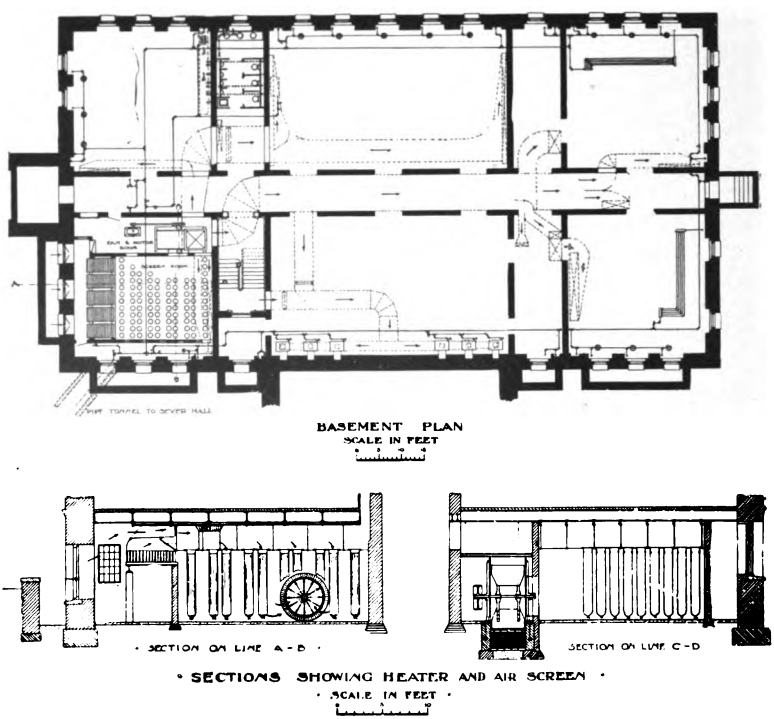
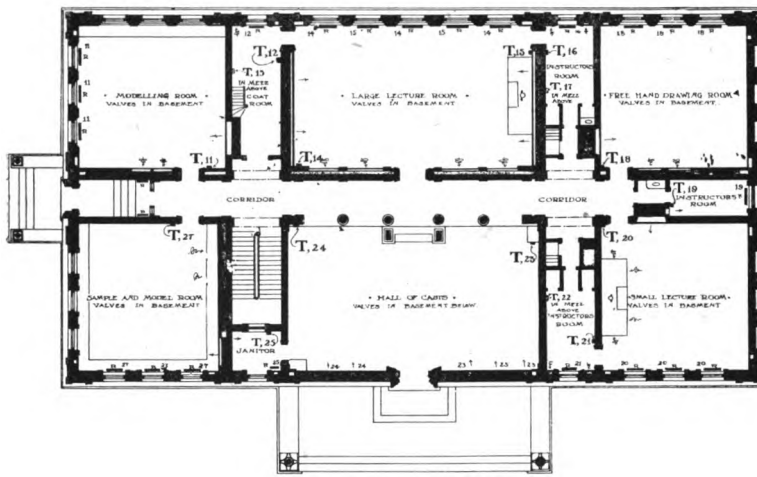


FIGURE 1.

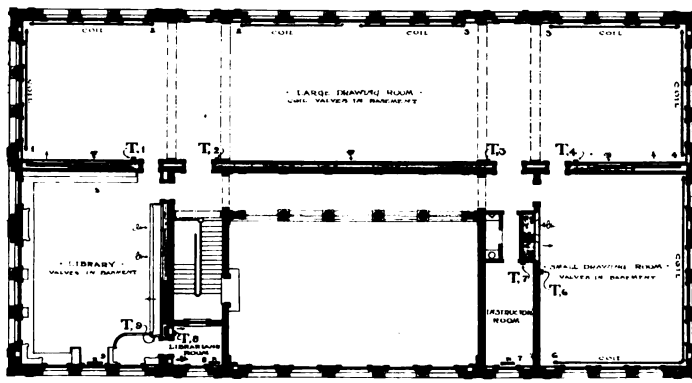
The building is primarily for day-time use but a few rooms are open in the evening, and an occasional evening lecture is given. The heating and ventilating system has been designed

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to heat the building independently of the ventilating so that the expense of introducing fresh air shall not be necessary to keep the building warm when unoccupied, or when used by so few



· FIRST FLOOR PLAN ·
SCALE IN FEET



· SECOND FLOOR PLAN ·

FIGURE 2.

that ventilation is not required. All the rooms, except the Hall of Casts, are heated by direct steam radiators or coils, and the air for ventilation is intended to be supplied at or about the

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desired temperature of the rooms. The direct radiators are automatically controlled and are intended to regulate the temperature when ventilating is necessary, thus making it possible to supply the air at a constant temperature. Steam is supplied from an adjacent building, Sever Hall.

The steam main from Sever Hall enters the basement of the building near the southwest corner, from which point two heating mains run on the basement ceiling, connecting at the northeast corner of the building. There is a separate main for the indirect radiators, and another main for the roof piping, described below. In the corridor, at the tunnel end of the building, a connection is taken out for supplying steam to the service hot water tank, and to a coil in the outlet duct from the basement toilet room. Valves are so located that the service water tank and the coil in the outlet duct may be supplied with steam even when steam is shut off from all the direct radiators in the building. The main to the indirect radiators and the main to the roof piping are also valved separately. The return from the direct radiators and that from the indirect radiators run back to Sever Hall separately. The risers to radiators on the second floor are located in chases left in the building walls for that purpose. In many cases the chases are made large enough to serve as outlet ducts for some of the small rooms, and the steam pipes in these chases are left uncovered.

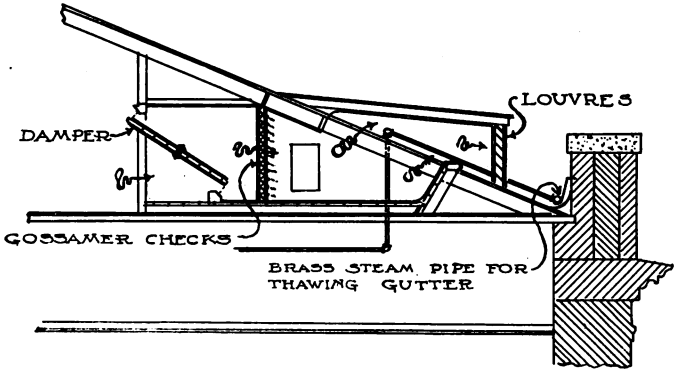
The radiators and pipe coils have been located as inconspicuously as possible, and in all the rooms, except a few small ones, more than one radiator or coil has been installed and the piping and valving is so arranged that a part of the heating surface may be turned off in moderate weather when the surface is not needed. In this way the frequent operation of the thermostats, due to an excess of heating surface, may be avoided, making the temperature of the rooms more uniform.

The Hall of Casts contains no direct surface, but is heated by six groups of indirect radiators, located in the basement, from which ducts lead to six registers in the outside wall of the room, near the floor. Air is supplied either from one of the main ventilating ducts connected with the fan or from an opening

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into the stair hall leading from the first floor to the basement, dampers being installed by means of which air may be taken either way desired. These radiators and ducts are indicated in Figure 1. The Hall of Casts may thus be heated by the air supplied for ventilating when the ventilating system is in operation or may be heated by "rotation" when the ventilating system is shut down. It should be noticed that the Hall of Casts opens into both the first floor and second floor hall so that the circulation through this room will keep all the hallways in the building warm.

In order to thaw out the gutters, which are behind a parapet, as shown in Figure 3, a steam main is run from the basement to the roof space, there connecting with four brass pipes which



SECTION THROUGH ROOF VENTILATOR

FIGURE 3.

run around the entire building in the gutters, supported by brass hangers soldered to the copper roof. All of the four connections to the roof pipes are valved separately so that the boilers may not be overloaded by turning steam into all the pipes at once after a heavy snow storm. At each end of the building these pipes run out through the outlet opening, as indicated in Figure 3, but on the sides they pass out through the roof and are provided with inverted copper cones to insure pre-

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vention of leaks from rain or snow. An idea of the appearance of the pipes in the gutters is indicated by a photograph, Figure 5.

The southwest room in the basement is reserved for ventilating apparatus. Five groups of cast iron indirect radiators are located near the fresh air openings into the building, being supported by a brick wall at the rear and an I-beam at the front, as is shown in Figure 1. The cold air passes up through these indirect radiators, or over them, according to the positions of two dampers, located one above and the other below, a galvanized iron partition between the top of the radiators and the ceiling. The two dampers are so connected that when one is open the other is closed, and they may be operated either by hand or automatically. The temperature of the ventilating air delivered to the building is governed by the movement of these dampers and may be adjusted with great accuracy. From the heating surface the air passes down through heavy cotton cloth screening bags, described below, to the fan. The fan, belted to an electric motor, delivers into a small pressure chamber from which three feeder ducts lead, one running nearly the length of the building on the ceiling of the basement corridor, which is furred down for it, the second running on the ceiling of the basement under the Large Lecture Room, and the third running on the ceiling of the screen room. From these three feeder ducts riser ducts for the various rooms are taken off. A damper is installed in each feeder duct and wherever branch ducts or riser ducts lead out of the feeder ducts, by means of which the amount of air going to any room or rooms, may be adjusted. Dampers are also installed in the riser ducts, for each room, controlled by chains in the basement, in order that air may be shut off from any room temporarily unoccupied. The riser ducts have been so installed as to interfere as little as possible with the appearance of the rooms, in the majority of cases being concealed in the walls, which are made thick for that purpose. The long narrow ducts were valuable in running electric conduits, the piping for the automatic control system, and even for plumbing pipes, making additional chases and slots in many cases unnecessary.

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The outlet ducts deliver into the space under the roof from which there is a special dormer outlet at each end, described more fully below. There is a damper at each of these outlets controlled by chains running to the basement.

In the installation of the automatic temperature control system precautions have been taken to eliminate as far as possible the danger of accidents and to minimize the trouble caused, should an unavoidable accident occur. Much trouble has been experienced with automatic temperature control systems, even with reliable thermostats and diaphragm valves, on account of leaks in the compressed air lines. The usual installation is essentially as follows: — a compressed air tank is located in the basement with a water pump which maintains a pressure in the tank of about 15 pounds per square inch. From the tank a main air line is run, with connections to the various thermostats taken off as found convenient. From each thermostat an air line is run to the valve or valves to be controlled by it. When the temperature at a thermostat rises to the point for which the thermostat is set a port is opened in the thermostat, admitting air from the main line to the diaphragm valve or valves controlled, which are thus shut. If the temperature falls at the thermostat the port is closed and at the same time the air in the diaphragm valve is released, and the valve is opened by the action of a spring. With this system of piping an accident on any part of the line will throw out of service all the thermostats in the building. In Robinson Hall the pump and tank are located in the fan room and a main air line is run to the cock-board, on the other side of the fan room. On this cock-board are located a pressure gauge and a number of cocks, one for each thermostat, and from each cock an independent air line is run to each thermostat. In this way an accident to any one air line affects only one thermostat; moreover, it is possible to easily locate the line on which a leak occurs by closing all of the cocks and then opening them one by one until the pressure on the gauge begins to fall. In a number of more recent installations the cock-board system of installation has been worked out rather more fully and has proved itself invaluable.

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The mechanism for controlling the mixing dampers is indicated in Figure 4. The axle of each damper comes through the brick wall into the motor room where the automatic diaphragm for controlling the dampers is located. On each axle is an iron arm, *a*, *a*, to which connection is made by means of a

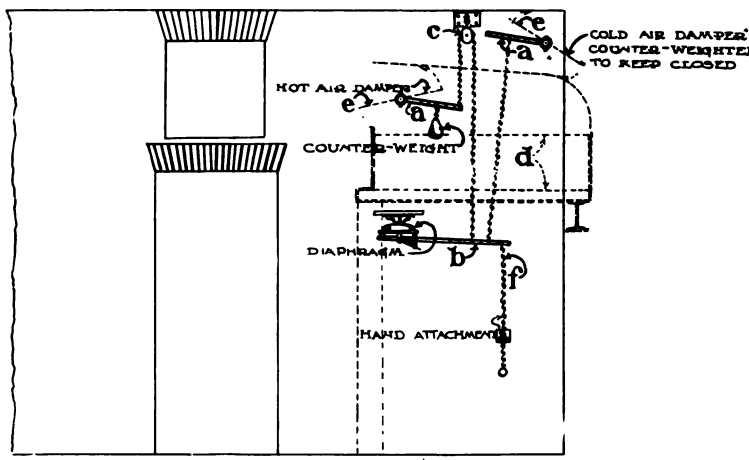


FIGURE 4.

chain with the arm of the diaphragm, *b*. One chain goes directly from the diaphragm to the damper arm and the other goes from the diaphragm arm to a pulley, *c*, and then down to the damper arm; both dampers are thus operated simultaneously. In the Figure the diaphragm, diaphragm arm, and the damper arms are shown in full, and the indirect radiators, *d*, and the dampers, *e*, *e*, are shown dotted. The chain, *f*, running down from the diaphragm arm is for controlling the dampers by hand, in case it should be desired to deliver hot air for a short time in the early morning for quick heating, or in case of accidents to the automatic temperature control system. The diaphragm is controlled by means of a thermostat located at the fan in the ventilating air and operates with a "graduated" action; that is

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to say, the dampers will assume a stationary position when the temperature around the thermostat reaches the temperature for which the thermostat is set, and from this stationary position they will move in either direction according as the temperature around the thermostat rises or falls, and when such a motion is caused the dampers will again assume a stationary position whenever the temperature for which the thermostat is set is again obtained. Usually, mixing dampers move to one or the other extreme position, when they once start, with the obvious result that they are moving constantly and that the temperature of the air delivered is undergoing constant variations, although the average may be that for which the thermostat is set. With the dampers in Robinson Hall, however, this difficulty is obviated. When the temperature at the thermostat changes the dampers will begin to move slowly, and if the temperature is changed sufficiently before the dampers reach their extreme position they will stop, while if the temperature changes beyond the point for which the thermostat is set the dampers will begin to move in the opposite direction, finally reaching a permanent position.

There are several features of the heating and ventilating installation which may be worthy of notice as different somewhat from many installations. The desirability of avoiding chimneys on the building, due to the architectural design, made it necessary to obtain concealed outlets through the roof for the ventilating system. This was done by means of two dormer outlets, one at each end, constructed as shown in Figure 3, and concealed by the parapets which surround the building. On the face of each dormer opening are copper louvres, a photograph of which is shown in Figure 5. Back of the louvres there is a copper pan from which a drip pipe runs to a waste connection. At the rear end of this pan are located gossamer air checks permitting the passage of air out through the opening, but closing against any back-draft. Large shut-off dampers of the butterfly type are employed, nicely balanced so that they are easily controlled by chains leading to the basement.

The use of screens for removing dust and dirt from the ven-

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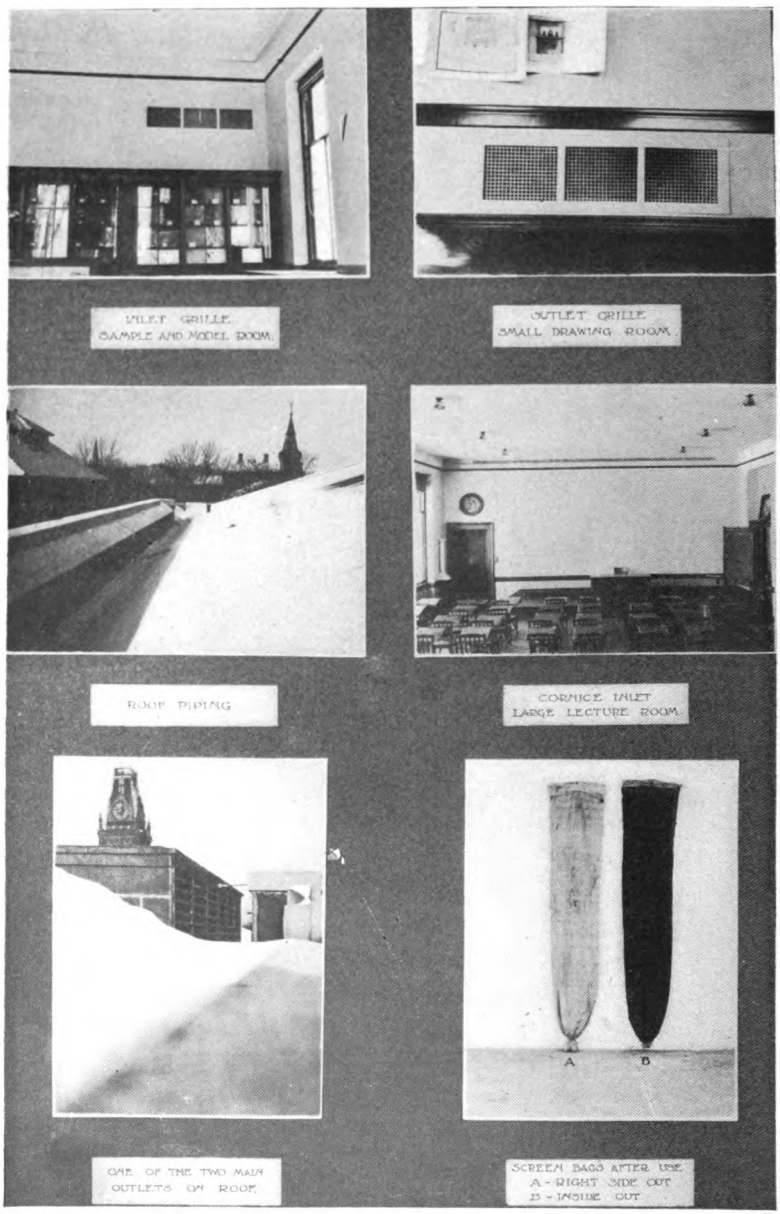


FIGURE 5.

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tilating air was a subject of controversy during the design of the system. The finish of the building, the light grilles, the plaster casts, etc., made it desirable that the building should be kept as free from dust as possible, but the location of the cold air inlet in the basement, surrounded as it is with grass, and being at some distance from any street, gave reason for belief that the small amount of dust which would be introduced through the ventilating system would be negligible. However, the small expense incurred by the introduction of the bag system and the desire to take every precaution against dust led to its adoption. This method of screening air is a modification of a form used by G. J. H. Woodbury of Boston, who holds letters patent for this apparatus. Bags were first used by Mr. Woodbury in a ventilating system where the air was taken from the roof to the basement through a large shaft, and the bags, four in number, were as long as the building was high. The system used in Robinson Hall is an adaptation of this principle to basement screen rooms and consists essentially of a large number of small bags suspended from collars in a galvanized iron false ceiling. The arrangement is indicated in Figure 1. The air is admitted above the galvanized iron ceiling and passes down through the bags, the entire surface of which acts as screening surface. The bags are attached to the iron collars by strings and can be easily removed for cleaning without spilling any of the dirt contained in them. The heavier dirt, in fact all but the very finest dust, drops to the bottom of the bags, which are so proportioned that the velocity through the tops is high while that through the sides is low. The advantages of this system are, simplicity and inexpensiveness of installation, simplicity of cleaning, infrequency of cleaning necessary, small room occupied, and large cloth area, making it possible to use heavy cloth. This last point is of great importance, since cheese cloth, often used for screening air, is ineffective, even when used double thick. One season of operation and inspection of the bags leads to the belief that they are remarkably efficient and that their omission would have been unfortunate. The dirt and dust collected in them would have caused serious damage to the

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grilles and the finish in the various rooms. In Figure 5 is shown a photograph of two of the bags in their present condition, one inside out and the other right side out.

In the design of the inlet and outlet grilles it was desired to obtain grilles which, though inexpensive, should be simple and as unobtrusive as possible. The grilles decided upon are of the square mesh, flat wire type, built on channel iron frames with flat iron flanges, and flat iron stiles dividing them into panels. They are set with the flanges lapping the plaster, and are, in general, painted to match the walls. In the case of the outlets in the Large Drawing Room where they come in the redwood wainscoting the finish is electro-bronze. Figure 5 shows photographs of grilles, one of an inlet and the other of an outlet. Wherever possible they are long and narrow, an advantage in appearance, in distribution of the air over the surface of the grille, and in the prevention of drafts. The inlet grilles for the Large Lecture Room are made of plaster, and extend nearly the whole length of each end of the room, as shown in Figure 5. Their design and location make them not only unobjectionable in appearance but leave room on the walls for a stereopticon screen at the one end and for hanging pictures, tapestries, etc., at the other, as was desired by the Department of Architecture. The ducts in the basement were so designed as to insure equal distribution all over the surface of the grilles, and measurements made of the velocity of the air at various points indicate a variation of about .5 of a foot per second in a velocity of about 7 feet per second. In connection with these grilles it is to be noticed that even a small amount of dust and dirt would cause serious trouble, and that freedom from such dirt and dust in this case is illustrative of the effectiveness of the bag screens.

The operation of the plant for one year has demonstrated that with proper care and attention, satisfaction, both as regards heating and ventilating, may be obtained. Anemometer measurements show that the amount of air supplied for ventilation, approximately 1,250,000 cubic feet per hour, is in accordance with the calculated amount before construction and is sufficient for the requirements of good ventilation. The arrangement

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and design of the inlets have been effective in preventing troublesome drafts. The heating system has proved efficient in the coldest weather. The system of automatic temperature control has proved valuable. It is sometimes expected that a system of heating and ventilating, in which an automatic temperature control system is used, should be absolutely automatic and should be free from all care and attention. This is a fallacy and all such systems should be given careful attention and regular inspection, the automatic part being of value in preventing discomfort from temporary overheating or underheating rather than in doing away with all attendance and inspection. The automatic control of the mixing dampers has been highly satisfactory but it has been shown inadvisable to attempt to temporarily alter the temperature for which the air thermostat is set, in order to supply heated air for an hour or two in the morning. The reason for this is that it takes some time to properly adjust this thermostat and that when once in adjustment it should not be disarranged. The hand attachment to the mixing dampers makes it possible to regulate the temperature of the air by hand when any temporary change in the temperature of the ventilating air is desired and this method of operation should always be used, it being necessary to turn off the cock leading to the air thermostat first.

The danger of overheating can be greatly reduced by turning off by hand a part of the radiating surface in moderate weather and thus preventing the constant turning on and off of the steam from a large amount of surface, which will produce temporary periods of discomfort from overheating even with perfectly working thermostats. Trouble from overheating is not only uncomfortable in itself, but also casts reflections upon the ventilating system, for a high temperature is popularly mistaken for closeness.

In maintaining a constant temperature of the ventilating air the division of the indirect radiators into five groups or stacks has been found convenient, as in moderate weather one or more of the groups may be shut off making the normal position of the mixing dampers half open. In order to prevent the possibility

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of freezing under such conditions bibb-cocks have been installed on the returns of the indirect radiators so that any group or stack not in use may be drained clear of water.

The heating and ventilating system, electric wiring, and plumbing, were all designed by the Engineers at the same time, it thus being possible to combine the various systems to their mutual advantage in convenience and economy of installation.

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THE VALUE OF METHODS OF APPROXIMATION.

JOSEPH RUGGLES WORCESTER, A. B. '82.

By far the most important part of engineering is the making of designs of one kind or another. Engineering also includes the observation of facts, and analyzing, arranging and digesting the facts observed. Another important duty of the Engineer is taking charge of the execution of work in accordance with his designs; but the chief use of the Engineer, and that in which his services are indispensable, is in designing. One of the requirements for admission to the American Society of Civil Engineers as a full member is that the candidate "shall be qualified to design as well as to execute engineering works."

The part of engineering which consists of observing, belongs chiefly to the surveyor, and the collation and digesting of observations belongs to the computer and scientist or mathematician.

The execution of designs often requires engineering skill, but this is not usually the case unless unforeseen contingencies are likely to arise, which can be met only by one qualified to modify the design in an emergency. Merely carrying out a design already prepared can be safely entrusted to the inspector and superintendent. They can interpret the plans and specifications and they can see that proper materials and workmanship are employed; but, when the unforeseen happens, when, in excavating, quicksand is encountered; or, when, in building the arch, the center begins to settle, or, when, in transporting a steel structure, it meets with a railway accident and some of the parts are bent; on such occasions there is apt to be a hurry call for the engineer.

What the engineer, and no one else, can decide, is how work shall be done; what assumptions shall be made with regard to probable forces to be encountered; what loads and stresses it will be safe to allow on different materials. His general foresight is required to determine the most effective, and, at the same time, economical way of accomplishing the end.

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In all this work, which is most truly engineering, methods of approximation are of the utmost service, and, in a surprisingly large proportion of cases, absolutely essential.

There is a widespread notion that engineering is a profession which deals with facts, and that its work is accomplished with mathematical precision; but this is only true in a relative sense. Possibly the engineer knows more precisely what he is doing than a clergyman or a physician, and can be more certain of attaining his desideratum. This may even be true with regard to a lawyer. The reason is that he deals with matter rather than mind, and matter is fortunately not so liable to freaks as mind. It is not, however, entirely free from freaks, or from circumstances, which, to our human intelligence, appear to be such, and, in dealing with freaks, exact methods are dangerous.

For example, an engineer is called upon to design a culvert through a railroad embankment to take care of a brook draining a certain tract of land. He may be supplied with the information obtainable from a long series of observations, as to the height which the water has reached in the brook previously. "The oldest inhabitant" can tell him exactly how high the water reached in "the great freshet of ——." He may know the area of the water-shed, and be supplied with a mass of information as to rainfall and weather conditions; but if he makes the capacity of the culvert exactly right for the worst known conditions, and fails to provide for freaks, such as the culvert being jammed with ice or debris, a cloudburst, the breaking of a dam further up-stream, or nobody knows what, he may get into trouble.

Or again, suppose an engineer is called upon to design a simple roof truss for a flat roof, and he were to assume that the maximum load that could come upon it were a snow load of perhaps twenty-five pounds per square foot, which, theoretically, would be ample, and a few years hence it should be found to be a point from which a football game or a procession could be viewed. Would he not thank his stars that he had not followed exact methods of calculation?

In another way, also, exact methods are sometimes dangerous. An engineer always regards with suspicion figures which are carried out to too many places.

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A survey in which angles are given to seconds, when the degrees are wrong, is much worse than one in which seconds are disregarded and the minutes are right.

The chief engineer of one of the largest bridge companies in this country once said to the writer, that when one of his assistants brought into him an estimate with the weight given to the last pound, he always said, "Never mind the pounds, are the tons right?"

It is no uncommon experience to find calculations made with extreme nicety, when the computer has forgotten to multiply by two, or even has mistaken the position of his decimal point. The effect of refinement in figures is often to obscure the main issue, and methods of approximation are much safer.

But aside from the dangers of exact methods, they can rightly be applied only to an extremely limited number of problems. Unless the data upon which the work is based is exact, no amount of accuracy in carrying out the deductions will avail to make exact results.

For an illustration, we may take the case of a simple girder for a railroad bridge. We may know how to calculate the strains from given loads (though possibly we do not), but let us see how near we are to obtaining an exact solution of the problem. In the first place, as to the loads: We know the weight of the heaviest engine now in use on the road and the spacing of its wheels. We realize that this engine will not run forever, or even as long as we hope the bridge will last, and that wheel loads are liable to increase, how much we cannot tell. So we assume that a possible load will be perhaps double the present. This is assumption No. 1. Then we know that when a train moves rapidly there is a certain, — or, rather, uncertain — shock produced. How much this may amount to, we do not know, but we will assume (No. 2) that it may be 50%. We then calculate the flange strain upon the foregoing assumptions, and are ready to determine what metal to employ. We intend to specify the use of soft steel, which will show, in test specimens, an elastic limit of 30,000 lbs. per square in., and an ultimate strength of between 54,000 and 62,000 lbs. per square in. We

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assume (No. 3) that if strained to 15,000 lbs. per square in., the metal would not deteriorate under repeated strains, but, to make absolutely sure, we assume (No. 4) as a safe-working strain, one-half of this, or 7,500 lbs. per square in. Here we have made four tremendous assumptions, and have not mentioned others, such as, that the workmanship will be perfect, that the steel will not be damaged in handling or by heating, and that the bridge will not deteriorate from corrosion, though it is no doubt true that some of the assumptions balance others. Now, with so many factors entirely assumed, can we expect that our final result will be more than approximate, if, indeed, it is even that?

If this is true with steel structures, it is even more so with other materials, for no structural material is more uniform or better known than steel. In wood, we have many doubtful conditions which do not exist in metal, such as knots, shrinkage cracks, and rot, both wet and dry. In masonry, stone, brick, mortar and concrete, there are uncertainties much more important than in steel. In fact, the longer an engineer's experience is in dealing with materials of construction, the more he feels the lack of an exact knowledge of what he is dealing with. In other branches of engineering besides ordinary construction, the case is similar. In dealing with foundations, in designing machinery, in hydraulic problems, in naval architecture, it will be found that the cases where you can obtain exact data, carry out your work by the use of exact methods, and obtain exact results, are extremely rare, if they can be found at all.

This being the case, should we not cultivate, in every possible way, the use of all methods of approximation which give results which are really approximate? A knowledge of exact methods is not to be despised. In fact, without knowing the exact method, one cannot be sure that any other is even approximately right, but the economy of labor and of time, which rough methods effect, will often enable an engineer to study a number of designs to see which is best, when, if he were obliged to work by exact methods, he would be forced to assume one plan and devote himself to that.

Many approximate methods are in general use at the present

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time, and they are being more widely adopted all the time, but there is still room for improvement in the same direction.

An example of this is in the use of the slide rule. This instrument, which has been known for nearly 300 years, has, in the last 15 or 20 years, been increasing in popularity to a phenomenal extent. When the Thacher cylindrical slide rule, which will give results to five places, was introduced about 15 years ago, bridge engineers were at first slow to believe that the results would be accurate enough to supplant arithmetical or logarithmic calculations, but they soon learned that the accuracy was all that could be desired. Now the smaller slide rules, that give results to three places, have become almost universally adopted for this class of work. The graphical method of computing strains, which was at first used only as a check upon analytical methods, is now almost wholly relied upon in the case of irregularly shaped structures.

Another striking illustration in the change that is going on in engineering methods is in the style of drawings which are now in use, compared with those of earlier years. In former times it was considered the proper thing to make a drawing on egg-shell paper, which had to be dampened and pasted to the board, to tint all parts with extreme nicety, to vary the weight of the lines, and to carefully cross-hatch sections and shade all curved surfaces, if not to wash in shadows. Now the common drawing is made on tracing cloth, without shading, and often out of scale. It is even the practice in many offices to sketch in lines free-hand.

On the other hand, an instance of where approximate methods are very slow of adoption is in the case of loads for railroad bridges. Railroad engineers insist, in a large proportion of cases, on their bridges being figured for actual wheel loads, which are based upon the locomotives in use on their roads. They do this notwithstanding the facts that types of locomotives are constantly changing, and that the enormous steel cars that are now coming into use often give as great or greater strains than the locomotives. Anyone who has calculated bridges for these actual wheel loads can appreciate how much

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labor could be economized if the railroad engineers would only specify uniform loads, approximately equivalent to the wheel loads, and they could do this without making assumptions worth considering in comparison with others they are bound to make.

Above all, however, the advantage of methods of approximation is to encourage and foster in the engineer the faculty of taking a broad view of his problem. They help him to lose sight of the petty details of his design, and to look at the main features in proper perspective. This is of extreme importance.

It has often been remarked how many men have risen to eminence in the profession of engineering, who started without technical education, and it is not easy for one who is devoting a number of years to a study of the details of the science, to see how this is possible. In fact, technical graduates are sometimes a little prone to look down upon their employers when they find that they are unfamiliar with the integral calculus of the "method of least work." They may find, however, that the same employer, with still less work, can discover flaws in their armor. They will find that he can tell, at a glance, approximately the true answer to their problem, through his intuition of the proper proportions. In the examination of existing structures, one is constantly filled with wonder at the marvelous achievements of men who know nothing of how to calculate stresses. To be sure, we also find examples of construction so fearfully and wonderfully designed, that the wonder is, how they have stood at all, and undoubtedly many of the works of the uneducated men have disappeared from view on account of their unscientific construction; but the fact remains, that engineers have lived, and are now living, whose knowledge and skill has not been derived from books and teachers.

This is no evidence that education is not of immense advantage, but only that the minor niceties of methods are of secondary importance compared to the attribute of common sense, which with some is inborn, but with many only acquired with long experience.

How to cultivate this faculty in those who are not naturally

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blessed with it, is one of the problems which engineering schools must struggle with. It may not be practicable to introduce a course of "Common Sense," though, if it were, it would be interesting to know whether it would be considered "soft" or the opposite. Undoubtedly it is the aim of every instructor to inculcate the faculty to the extent of his ability in all he teaches, but one of the greatest aids in reaching this object would be to show wherein approximate methods may be safely adopted, and the adoption of them when possible.

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ARMATURE DROP AND REGULATION OF ALTERNATORS.

COMFORT AVERY ADAMS.

Assistant Professor of Electrical Engineering.

(Continued from page 167.)

[NOTE. The following further explanation of the formula for the armature m. m. f., A, (see pages 155 and 157), is given by request.

In the two pole machine there can be no difficulty, and in the transition to the multipolar type it is only necessary to keep in mind that we are dealing with a single complete magnetic circuit, and that A represents the average armature ampere turns linked with that magnetic circuit, i. e., the average armature ampere turns per pair of poles, or the average ampere conductors per pole.

Referring now to formulae (3), (5) and (6) it will be observed that $\frac{N_a I_a}{2p'}$ is the number of r. m. s. ampere conductors per pole, the constant .707 being necessary to reduce the r. m. s. value to the average. In this average, direction as well as magnitude is taken into account, i. e. it is the average of the components in the average direction, (see pages 155 to 157).]

Figures 12 and 13 show the magnetic circuits of the two alternators considered in examples 1 and 2 on pages 164 and 165, and figure 14 that of an inductor alternator, considered in example # 3, which follows. These illustrations will show roughly the relation between ϕ' and the shape of the slot.

Example # 3. 780 K. W. 2 Phase Inductor Alternator.

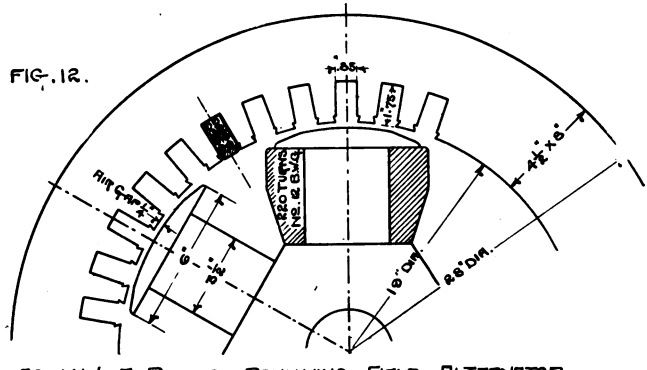
This example is given to illustrate an entirely different type of machine, one in which the relative effects of armature reactance and armature reaction are quite different from those of the preceding examples, and one in which saturation of the magnetic circuit plays an important part.

Frequency 60 cycles; 40 north poles on one side and 40 south poles on the other side of the armature; 90 r. p. m.; 2450 volts; 160 amperes per phase; 160 slots on each side of the armature; 2 slots per north pole per phase on one side of armature, or on the basis of the alternate pole type, one slot

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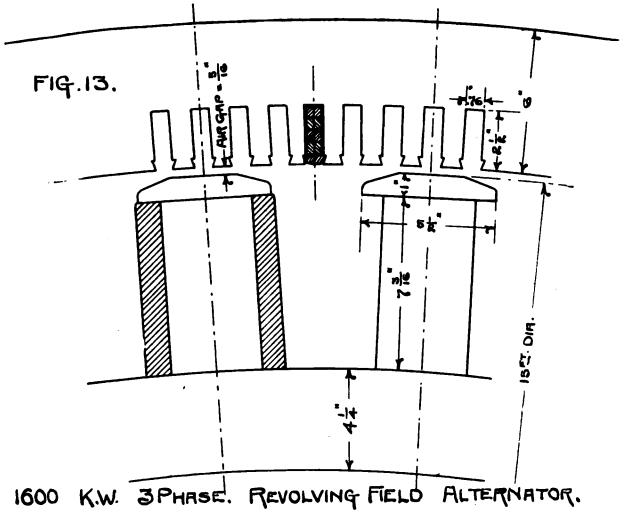
per pole per phase; 10 conductors per slot; imbedded length of conductors = 9.4″; ohmic resistance of armature per phase = .33 ohms hot; equivalent resistance per phase = .45 ohms (assumed); owing to the wide, open slots and short end connec-

FIG. 12.



50 K.W. 3 PHASE. REVOLVING FIELD. ALTERNATOR.

FIG. 13.



1600 K.W. 3 PHASE. REVOLVING FIELD ALTERNATOR.

tions, ϕ' will be less than in the first two examples, say 7 lines per ampere inch; then the reactance per phase will be,

$$X_a = \frac{2\pi \times 60 \times 7 \times 9.4 \times 10^2 \times 160}{10^8} = 4 \text{ ohms.}$$

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The excitation is supplied by a single coil of 362 turns, and the observed saturation curve is shown in figure 15.

The calculation of the armature reaction for this type of machine needs a little explanation. A diagrammatic sketch of the magnetic circuit is shown in figure 16, from which it may be seen that in passing around the magnetic circuit once, (from

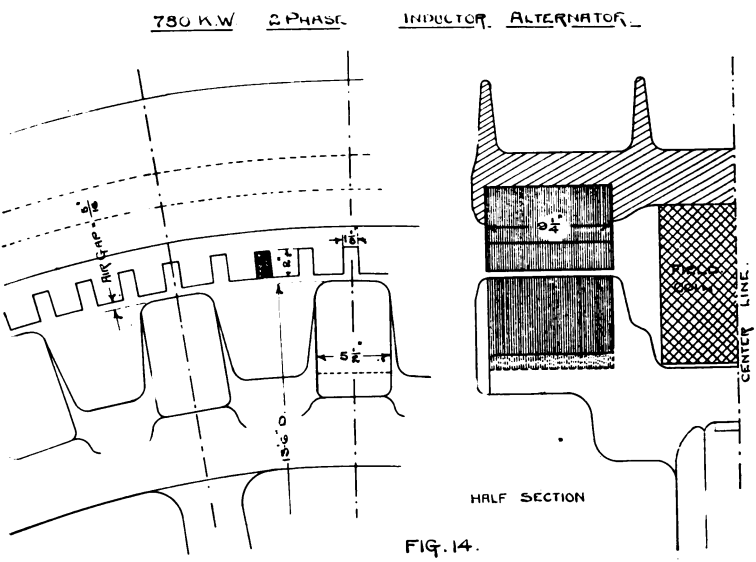


FIG. 14.

a north pole into the armature on one side, out on the other side into the opposite south pole, and around the field coil), line $\overline{abc}$ of the diagram, the flux is linked with the same number of armature ampere turns as if, in a machine of the alternate pole type, the flux were to pass into the armature on one side from a north pole and out from the same side into the adjacent south pole, line $\overline{adf}$ of the diagram.

Therefore in calculating A by equation (5) page 157, N_a should be taken as the number of conductors on one side of the armature, and 2p' as the number of poles on both sides. Thus at full load of 160 amperes —

$$A = .707 \frac{160 \times 160 \times 10}{80} = 2260 \text{ ampere turns.}$$

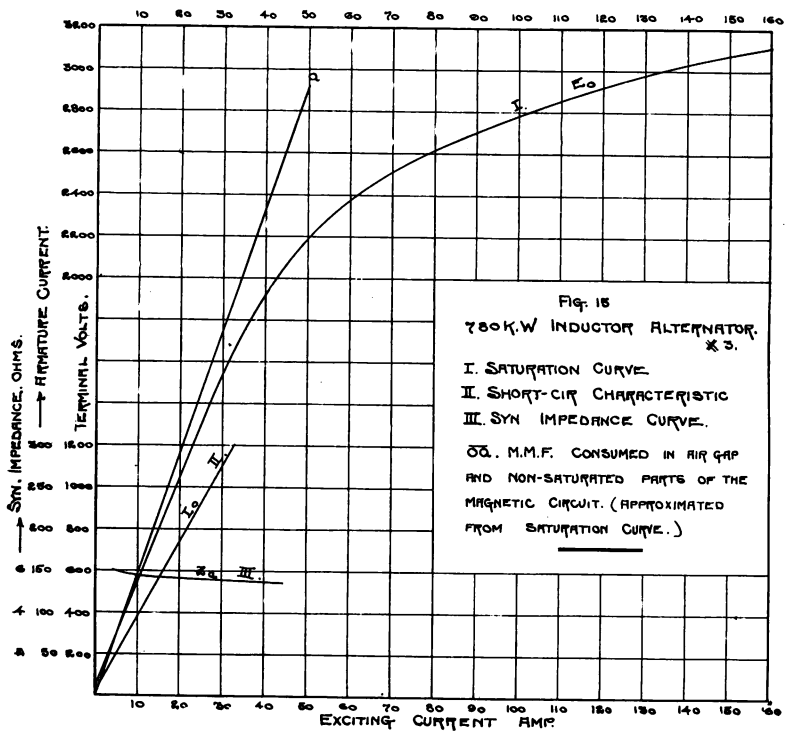
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Reduced to field amperes, A = 2260 ÷ 362 = 6.25 amperes.

Excitation at full non-inductive load. See figure 17.

$E = 2450.$
$I r_a = 160 \times .45 = 72.$
$I x_a = 160 \times 4 = 640.$
$E_a = \sqrt{2522^2 + 640^2} = 2600.$

The corresponding field current taken from the saturation



curve, figure 15, is 77.8 amperes = R; lay this off perpendicular to E_a; add $-A$ to R geometrically and get F = 79.5.

The saturation is so considerable that it becomes desirable to

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investigate the effect of the increased leakage. This is more important here than in the ordinary type of alternator, since a considerable part of the leakage flux not only saturates the magnetic circuit and demands additional field ampere turns, but also enters the armature at a point such that the resulting e. m. f. is in opposition to the useful e. m. f., making it necessary that the latter, and therefore the useful flux, be increased above the value corresponding to E_a. The increased leakage in the inductor alternator thus counts twice in demanding increased excitation.

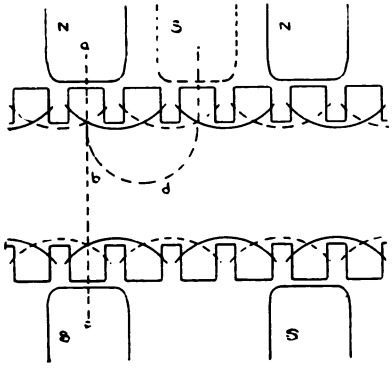


FIG 10.

In the ordinary type of alternator with alternate north and south poles, this increase of the flux takes place only in the field cores and yoke, and it would therefore be necessary to know the relation between the flux and the m. m. f. consumed in the field cores and yoke in order to determine the extra m. m. f. demanded in these parts by the extra leakage. This is shown for an imaginary case in figure 8, page 162. If this curve is not at hand, it can be approximated, if we can reasonably assume that within the normal range of operation saturation takes place only in those parts of the magnetic circuit which carry the leakage flux.

Draw a straight line through the origin and slightly above the straight part of the saturation curve; this will represent roughly the m. m. f. consumed in the air gap and in the non-saturated parts of the magnetic circuit, the remainder being the m. m. f. consumed in the saturated parts. The former is shown by the straight line $\overline{oa}$ in figure 15, and the latter by the difference between the saturation curve and $\overline{oa}$.

This approximation is more legitimate in the inductor alternator than in the alternate pole type, since in the former a

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part of the extra flux effects all parts of the main magnetic circuit (as explained above) and the other part avoids only that part of the magnetic circuit which is in the vicinity of the armature counter m. m. f.

The only case therefore where any considerable error would be introduced by this approximation would be in a machine with highly saturated iron in the vicinity of the air gap.

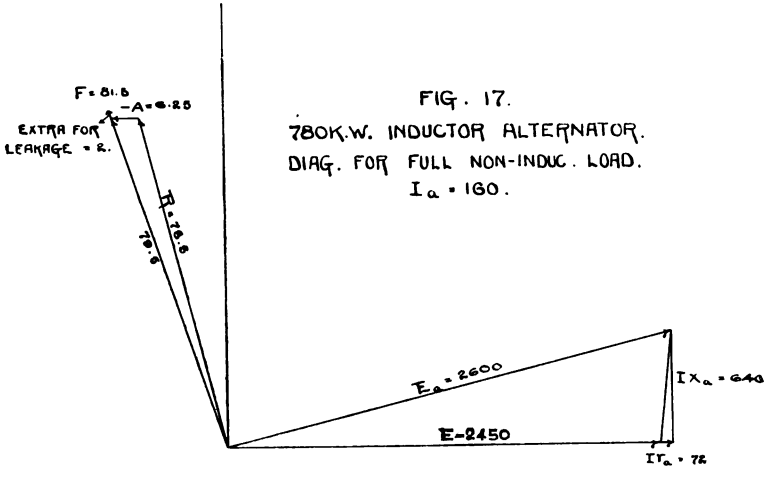


FIG. 17.
780K.W. INDUCTOR ALTERNATOR.
DIAG. FOR FULL NON-INDUC. LOAD.
$I_a = 160$.

With this understanding we can proceed to the determination of the additional excitation for extra leakage.

The ratio of F to R is 1.022 ; if the no load leakage coefficient be assumed at 1.35, which is reasonable for this type of machine, the full load leakage coefficient will be $1 + .35 \times 1.022 = 1.358$, and the ratio of the total flux to that necessary to produce the e. m. f., E_a, on open circuit, will be $1.358 \div 1.35 = 1.005$, or an increase of .5 %.

Thus the flux in that part of the magnetic circuit whose m. m. f. is represented by the difference between the abscissas of

[1] This ratio is unusually small in this case and the corresponding correction would be negligible were it not for the extreme saturation. Even thus the correction will be found to be quite small, less than in machine #2, see figures 26 and 27.

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the saturation curve and those of the line $\overline{oa}$, have been increased by .5% from the point corresponding to 2600 volts. A close inspection will show that this increase corresponds to an increase of about one ampere of field current, but as a large part of the leakage counts twice in the inductor alternator, this should be doubled.

Any error introduced into this correction by assuming no saturation in the vicinity of the air gap will not be serious except in an extreme case, since the whole correction is not large. Neither will a probable error in the leakage coefficient have much influence.

The total full load field current is thus

$$F = 79.5 + 2 = 81.5 \text{ amperes.}$$

The observed current necessary under the above conditions was 80.8 amperes.

Regulation. The open circuit e. m. f. corresponding to 81.5 amperes field current is, from the saturation curve, 2640 volts and the regulation

$$\frac{2640 - 2450}{2450} = \frac{190}{2450} = 7.75\%.$$

The observed regulation was 7.4%.

This agreement, which is good, depends largely upon the choice of ϕ', but a consideration of the above three examples will show that with a moderate range of slot proportions, the range of ϕ' is also moderate and not difficult to approximate after a little experience.

There is, however, a very simple method of measuring the leakage reactance, and therefore ϕ', indirectly, by means of the short circuit characteristic.

Experimental Determination of Leakage Reactance.

At short circuit the general diagram reduces to that shown in figure 18, where the generated e. m. f., E_a, is entirely consumed by internal impedance.

Since x_a is large compared to r_a, R and $-A$ will not differ much in direction and we have the approximate relation, R =

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F − A. But F is given by the short circuit characteristic and A can be calculated from the corresponding armature current. R is thus approximately determined, from which E_a may be obtained by means of the saturation curve. Thus as r_a and I are known, x_a can be readily calculated, as follows:

$$x_a = \frac{\sqrt{E_a^2 - I^2 r_a^2}}{I}$$

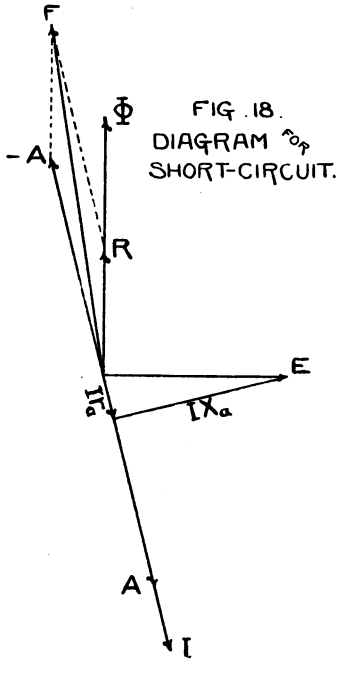


FIG. 18. DIAGRAM FOR SHORT-CIRCUIT.

For any short-circuit current within the heating limit, the values of E and Φ are so small that the teeth and pole faces are not appreciably saturated; therefore the reluctance of the leakage path is less than when running normally and the leakage reactance is correspondingly greater. This error is, however, very small except in cases of extreme tooth saturation, since much the greater part of the reluctance of the leakage path is in the slot.

Examples of the Determination of x_a from the Short Circuit Characteristic.

First consider the 50 K. W. alternator of example # 1, p. 164. Its saturation and short circuit curves are shown in figure 19.

Take the point on the short circuit curve corresponding to an armature current of 160 amperes; then,

A = .707 × 48 × 160 = 5430.0 ampere turns, or reduced to field amperes this is,

$$A = \frac{5430}{460} = 11.8 \text{ amperes field.}$$

The value of F corresponding to 160 amperes armature is found from the short circuit curve to be 13.5 amperes, and the difference is

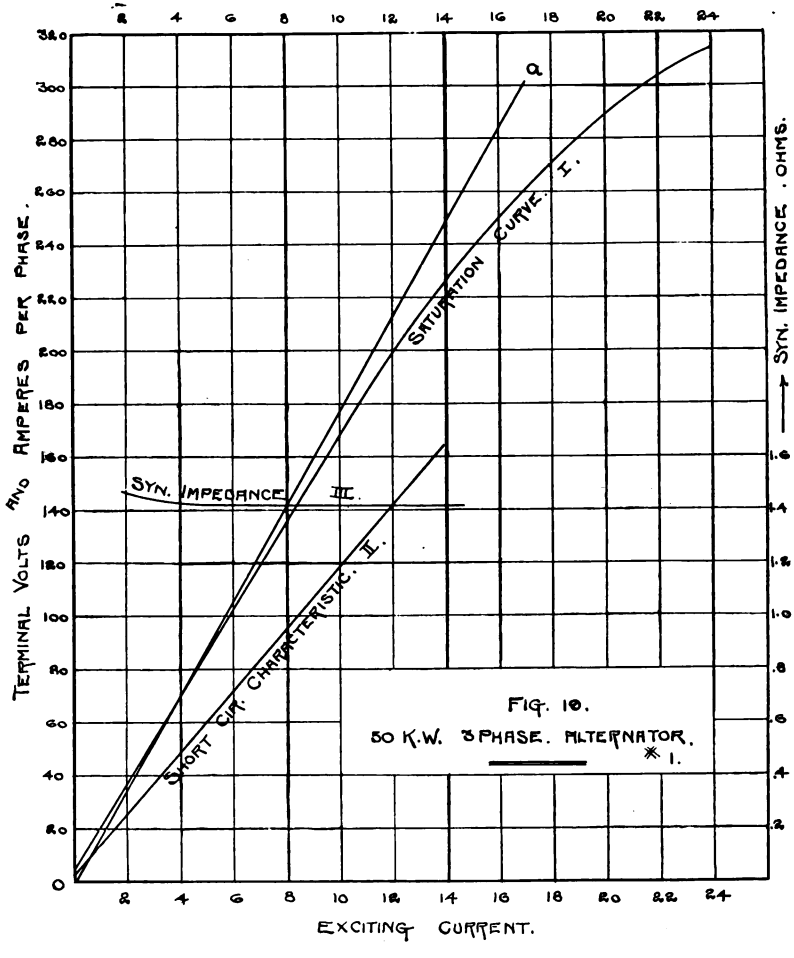
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$$F - A = R = 1.7 \text{ amperes.}$$

This corresponds on the saturation curve to 31 volts. Then,

$$z_a = \frac{31}{160} = .193 \text{ ohms}$$

$$\text{and } x_a = \sqrt{z^2 - r_a^2} = .182 \text{ ohms.}$$



This corresponds to $\phi' = 8.6$, and if this value had been used in example #1 in place of $\phi' = 10$, the calculated values

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of F and of the regulation would have agreed more closely with the observed values.

A considerable error in the choice of ϕ' for this particular case, would not have produced any considerable error in the result, since the reactance plays such a small part as compared with the armature reaction, see Figure 9, page 164. The short circuit diagram drawn to scale for this case, is shown in Figure 20.

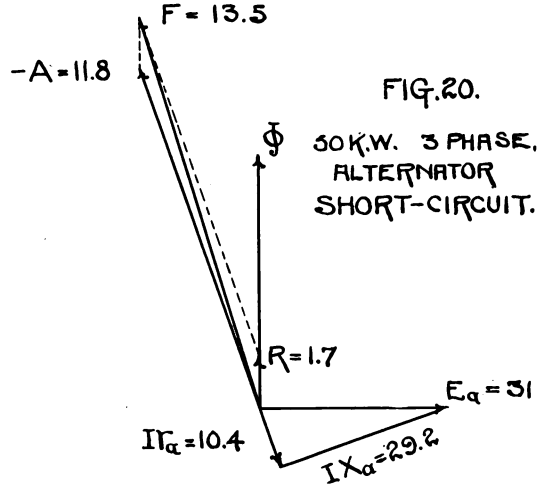


FIG. 20.
50 K.W. 3 PHASE, ALTERNATOR SHORT-CIRCUIT.

Owing to the large value of $\frac{F}{R}$ at short-circuit, there is very considerable increased leakage, for which correction should be made; but owing to the small flux and low densities in the parts affected (the field cores and yoke), the extra ampere turns required in these parts by the extra leakage is relatively small.

The method of making this correction is as follows. Let $\nu_0 = 1.3$ be the no load leakage coefficient; $\frac{F}{R}$ at short circuit will be $= 8.$, (this corresponds to figure 20 and is unusually large), then the short circuit leakage coefficient will be $1 + .3 \times 8 = 3.4$, and the flux through field cores and yoke will be $\left(\frac{3.4}{1.3}\right)$ 2.6 times

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as great as when there is no armature counter m. m. f. This means an increase in the ampere turns consumed in field cores and yoke, which increase can be taken from the curve showing the ampere turns consumed in those parts, see figure 8, page 162.

In the present case this curve is not known, but may be approximated as in Example # 3; see figure 18, where the horizontal distance between the saturation curve and the line $\overline{oa}$ may be taken roughly as the m. m. f. consumed in the field cores and yoke, on the assumption that the remainder of the magnetic circuit is not saturated.

The increase thus found is about .2 amperes which, subtracted from F, gives 13.3 amperes. R is therefore 13.3 – 11.8 = 1.5 amperes. But if A had been subtracted from F geometrically, the result would have been R = 1.6 amperes, which brings it back to more nearly its original value. The corresponding $E_a = 30$ in place of 31, and $x_a = \frac{28}{160} = .175$ in place of .182.

This correction which is unusually large, has almost no effect upon the calculated excitation or regulation. Fortunately, whenever $\frac{F}{R}$ (at short circuit) is large and there is consequently a relatively large correction in x_a, the importance of the latter is relatively small (as in the above case), and a considerable error therein has little effect on the excitation and regulation calculated thereby.

In any case this correction in the calculation of x_a is a refinement hardly in accord with the roughness of the method, although the same correction may be very important when applied to the determination of the regulation.

As a second example consider the calculation of x_a for the 780 K. W. inductor alternator of example # 3.

The saturation and short-circuit curves are shown in figure 15.

Take the point on the short-circuit curve for 200 amperes armature current, and field current equal to 21.6 amperes.

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$A = .707 \frac{200 \times 160 \times 10}{80} = 2825$ ampere turns, or reduced to field amperes $A = \frac{2825}{362} = 7.8$ amperes.

$$F - A = 21.6 - 7.8 = 13.8 = R.$$

From the saturation curve the corresponding induced e. m. f. is $E_a = 760$ volts, and $z_a = \frac{760}{200} = 3.8$ ohms.

In this case the difference between x_a and z_a is so small (less than 1%) that no account need be taken of it. We therefore have $x_a = 3.8$, which corresponds to $\phi' = 6.65$. Had this value of ϕ' been used the results would have agreed equally well with the observed results, but a little too low instead of too high.

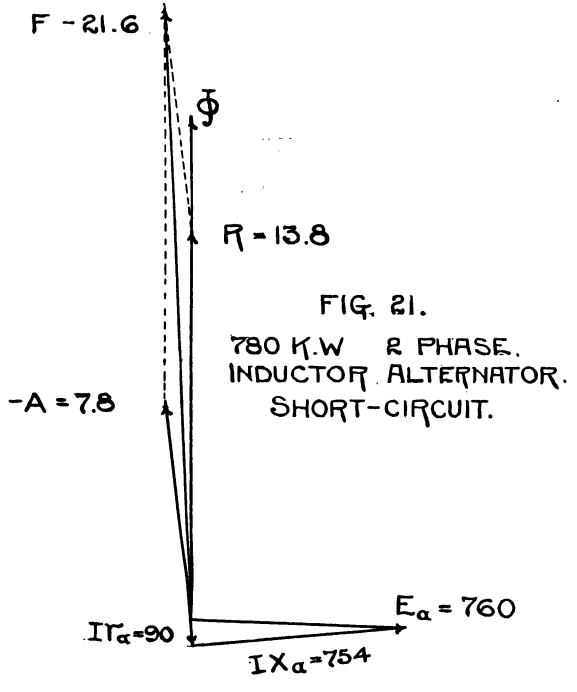


FIG. 21.
780 K.W 2 PHASE.
INDUCTOR ALTERNATOR.
SHORT-CIRCUIT.

The short circuit diagram drawn to scale for this example, is shown in figure 21.

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Second Method of Measuring the Leakage Reactance.

The following method is more rigid than that given above, although not so simple to carry out.

Load the machine with as nearly a pure inductive load as possible, a power factor of .6 will be fairly satisfactory; adjust the excitation to that of about normal full load; read exciting current, armature current, and terminal e. m. f.

The vector diagram will look something like that of figure 22.

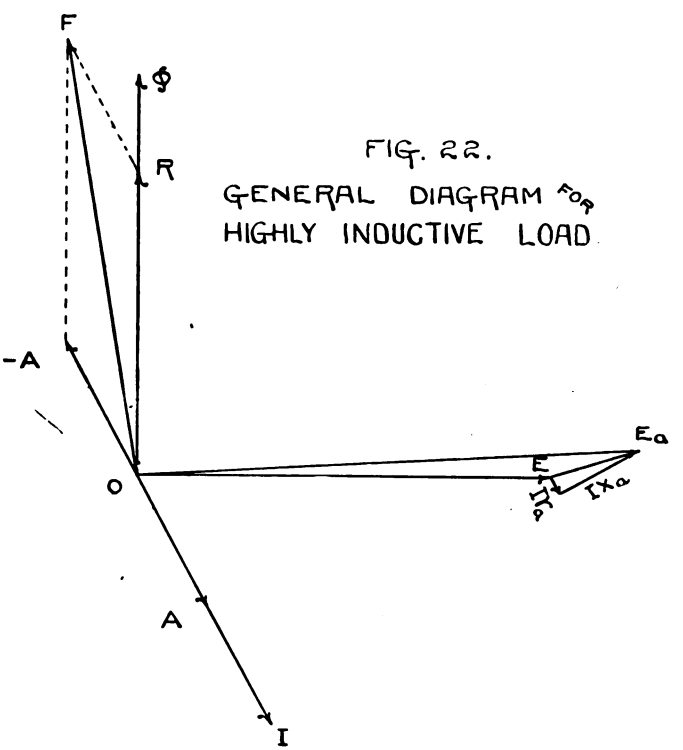


FIG. 22.
GENERAL DIAGRAM FOR HIGHLY INDUCTIVE LOAD

Subtract A from F to get R; look up E_a on the saturation curve; from E_a subtract E to get Iz_a; then $x_a = \sqrt{z_a^2 - r_a^2}$.

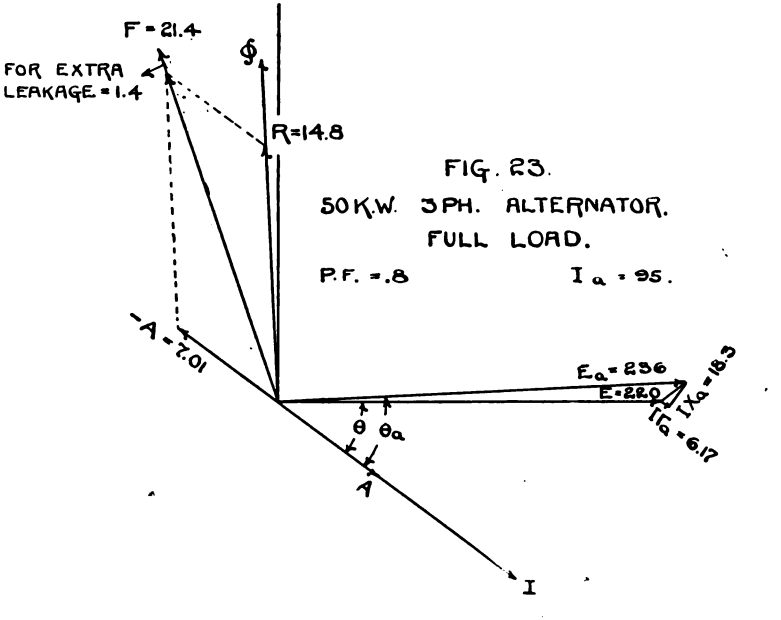
If the load is highly inductive the above subtractions may be made numerically.

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The advantage of this method is that the magnetic circuit is normally saturated and the leakage reactance normal.

Moreover, the reactance thus obtained includes the effect of increased leakage, (unless correction for the latter is made), but although this effect increases with the magnitude and lag of the current just as does the effect of the true reactance, and might therefore be taken account of by an increase in the value of x_a used in calculation, it is also dependent upon the slope of the saturation curve at the point in question and thus varies from point to point.

In cases where the increased leakage does not play an impor-



tant part, it is sufficiently accurate to thus include it in the value of x_a as measured by the above method.

Excitation and Regulation with Inductive Loads.

It will be instructive now to determine the excitation and regulation of these same machines under inductive loads. The

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only changes in the diagrams are that I is larger for the same power, and lags behind E, and that therefore Ir_a, Ix_a, and A are shifted around by the same angle. The values of x_a used will be those obtained from the short circuit characteristic by the first method described above.

The diagrams, figures 23, 24, and 25, speak for themselves. The resulting values of F for the three machines are as follows.

Machine.	F in Field Amperes.	Regulation in %.	Increase in F due to increased leakage.	Corresponding Regulation.
# 1	20	31.5	.54	33.5
# 2	200	14.5	24.	18.
# 3	146	24.5	13.	26.3

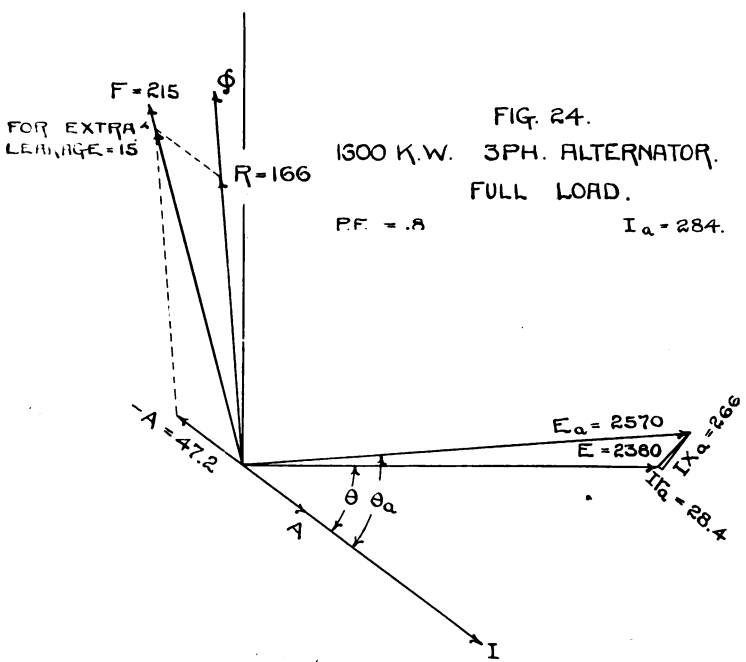


FIG. 24.
1500 K.W. 3PH. ALTERNATOR.
FULL LOAD.
P.F. = .8 I_a = 284.

The effect of increased leakage is quite appreciable in all of these cases owing to the increased ratio of $\frac{F}{R}$.

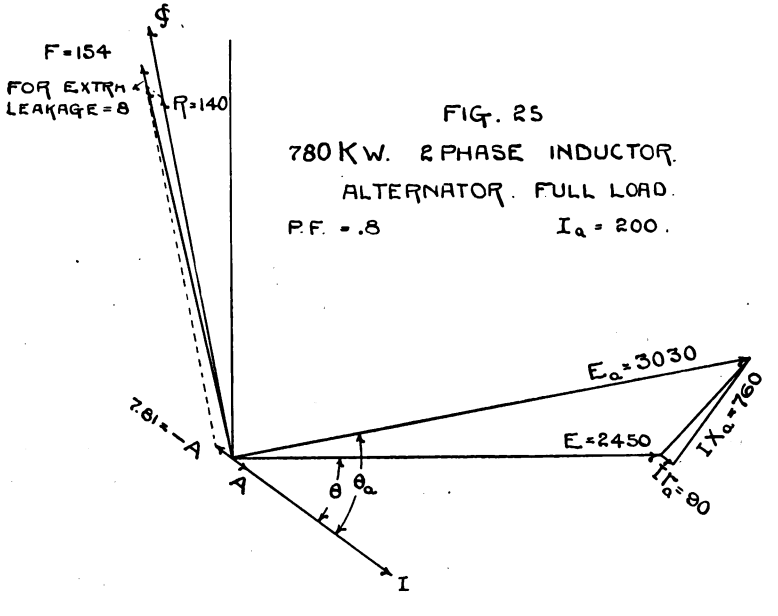
It should be noted here that in a machine such as # 3 with small armature reaction, the ratio of $\frac{F}{R}$ is less, and this correction

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would be less than in a machine with a large armature reaction, were it not for the high saturation. In general it may be stated that the magnitude of this correction varies directly with the armature reaction, the degree of saturation of the field cores and yoke, and the no load leakage, other things being equal.

Comparison of Results.

The six diagrams, figures 9, 10, 17, 23, 24, and 25, show very clearly the distinguishing difference between the alternate pole type of machine and the inductor alternator, namely, that whereas in the former type, (figures 9, 10, 23, and 24), the



armature reaction predominates, in the latter (figures 17 and 25), the armature reactance predominates, in producing the armature drop.

The chief reason for this difference will be seen by an inspection of figure 16; thus, if south poles were introduced between the north poles on one side of the armature, and the

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other half of the machine removed entirely, there would result an alternate pole machine of approximately the same e. m. f. and current capacity, the same armature reaction, but only one half the reactance and resistance. This comparison standing by itself might give a wrong impression of the relative merits of the two types, for there are many compensating advantages of the inductor type.

Effect of Saturation Upon Regulation.

The chief purpose of saturation in the magnetic circuit of an alternator is to improve its regulation.

Keeping in mind the definition of regulation, (the percentage rise in terminal e. m. f. when the full load is thrown off), an inspection of the general diagrams (figures 23, 24, and 25) will show clearly the sources of this rise of terminal e. m. f. and its relation to the saturation of the magnetic circuit.

One source is the setting free of the e. m. f. consumed by armature impedance; the other the making available of that part of the field m. m. f. required to balance the armature m. m. f., and its application to the increase of flux and e. m. f.

The first of these sources of increased e. m. f. is independent of any question of saturation, except in so far as the tooth saturation affects the value of x_a.

But the second is wholly dependent upon the degree of saturation, a high saturation throttling the effect of the increase of available m. m. f., and thus reducing the otherwise rise of pressure.

The saturation of the magnetic circuit is therefore effective towards improving the regulation only so far as the armature reaction is concerned, but cannot eliminate the effect of armature reactance.

From this it is clear that in machines with relatively large armature reactance, such as that of example # 3, saturation is less effective than in machines with relatively large armature reaction such as those of examples # 1 and # 2. This accounts

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for the fact that although the saturation of # 3 is far greater than that of # 2, the latter has far better regulation.

The case of # 3 is an extreme one, owing to the low speed (90 r. p. m.) of its prime-mover to which it is direct-connected. This speed is especially low for this type of machine which is particularly suitable for high speeds. At an appropriate peripheral velocity, which could easily be double that of the present machine, the length of active conductor, and therefore the resistance and reactance, could be reduced to about one half of the present values, which would reduce the regulation to below 5 per cent.

The reason for the poor inherent regulation of # 1 is that it has a very large armature reaction and low saturation.

Thus far only the *advantages* of saturation have been considered, but there is a considerable danger of pushing saturation too far, especially in machines with large leakage, namely, that due to the effect of the increase of leakage as the load increases. This effect has already been described and determined, (see pages 161–162, and 258–260).

It has also been pointed out (page 269) that, other things being equal, this danger is greater the greater the ratio of $\frac{F}{A}$, that is, the greater the armature reaction.

It thus appears that the type of machine in which saturation is the most effective in improving regulation, is also the type in which there is the greatest danger of over-saturation due to the increased leakage.

But this danger occurs only when the saturation takes place in those parts of the magnetic circuit that carry the leakage flux, namely, the field cores and yoke. If, therefore, the armature cores could be saturated, the advantage would be secured without the corresponding disadvantage, but the resulting core losses would be prohibitive. In the inductor alternator the armature core back of the teeth does not, for the most part, experience any considerable change in flux density, but in this type of machine this same part of the armature core carries the leakage flux, so that the armature core cannot safely be pushed very high as to density even in the inductor alternator.

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Thus the only part of the magnetic circuit in which the advantage of saturation can be obtained without the corresponding disadvantage, is that in the vicinity of the air gap and armature conductors, namely, the teeth and pole faces, although even here an appreciable increase of hysteresis and eddy current losses is entailed.

To sum up, the requirements for good regulation are: —

(a) Small armature leakage reactance.

(b) Small armature reaction.

(a) The reactance depends chiefly upon

(1) The length of active or imbedded conductor.

This can be reduced by increasing the average gap density, or the peripheral velocity.

(2) The number of conductors in a slot, and the shape of the slot.

The number of slots should be as large as possible; each slot should be as broad as possible and open at the top rather than partly or wholly closed.

(b) Since the actual number of armature ampere turns per pair of poles is determined by other considerations than that of armature reaction, attention should be turned to the reduction of the *effect* of the armature m. m. f., which effect depends chiefly upon

(1) Its ratio to the field m. m. f., F, and this ratio can be reduced by increasing F.

(2) Saturation of the magnetic circuit.

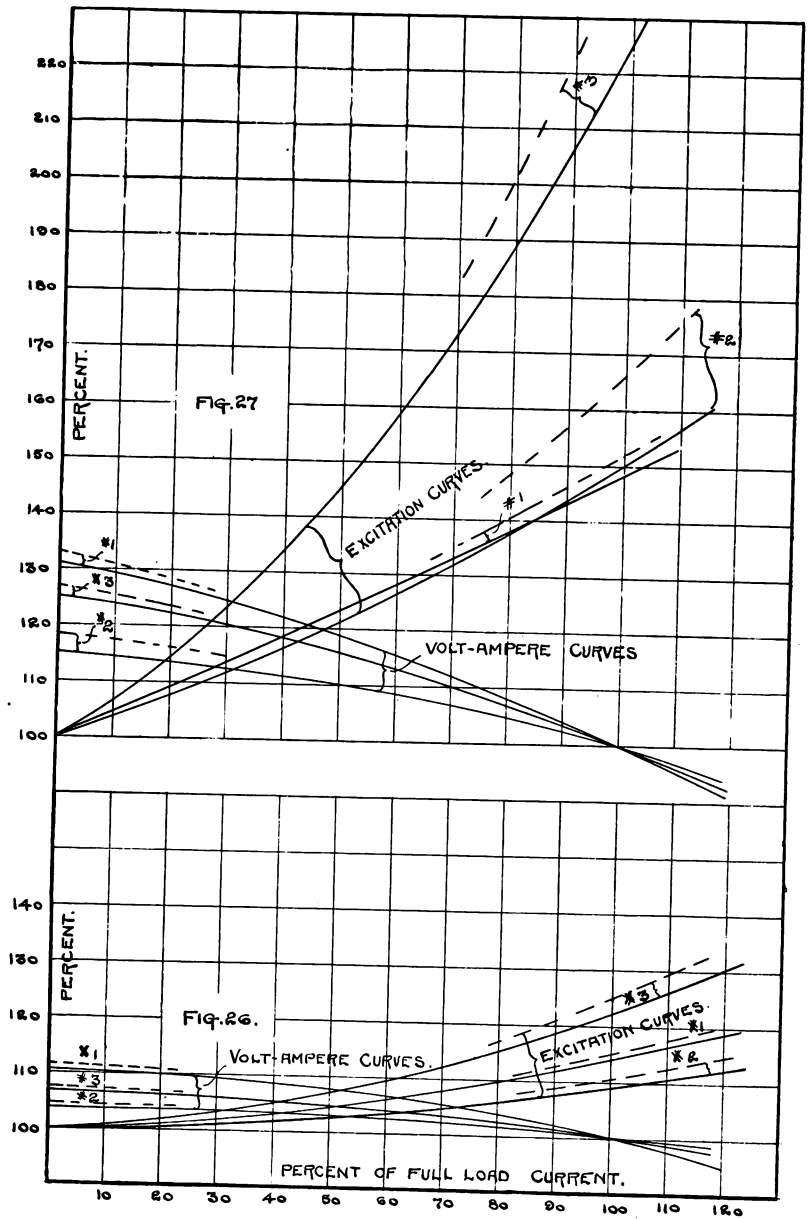
This should be moderate except in the vicinity of the air gap.

Of course there are other considerations not relating to regulation which make it sometimes inadvisable to utilize all of the above mentioned devices.

The two sets of curves in figures 26 and 27 will show some of the characteristic features of the three machines above considered a little more clearly than did the individual points previously calculated.

The *excitation curve* is the field current necessary to maintain constant terminal e. m. f. under varying armature currents, plotted against the latter.

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The *volt-ampere curve* is the terminal e. m. f. plotted against armature current, with exciting current kept constant at the value necessary to maintain normal terminal e. m. f. at full load.

The curves of figure 26 are for non-inductive loads and those of figure 27 for inductive loads of power factor = .8. For the sake of comparison these curves are plotted in per cent. The armature current is plotted in percent of the full load value, the excitation in percent of that necessary to maintain the normal e. m. f. at no load, and the terminal e. m. f. in per cent of its normal value.

The full line curves are the results of calculations which neglect the effect of extra leakage, and the broken curves above include this effect. It will be observed that the intersection of the volt-ampere curves with the vertical axis, gives the regulation directly for the several cases.

One interesting comparison is between the two kinds of curves. Although # 3 has a much better regulation than # 1, as shown by the volt-ampere characteristics, the percentage increase of exciting current from no load to full load is much greater in the former case.

The reasons for this are, high reactance and high saturation; the former making necessary a considerable increase in the induced e. m. f., E_a and in the flux, and the latter requiring a relatively large increase in m. m. f. to produce this increase in flux. This is much more marked in the curves for inductive load, where the reactance counts still more heavily.

The same cause is operative in making the inductive excitation characteristic of # 2 cross that of # 1 at full load, although the regulation of # 2 is more than twice as close as that of # 1.

Another interesting point is that with high inductive loads the correction for extra leakage is greater for # 2 than for # 3, owing to the larger armature reaction of the former, coupled with a considerable saturation.

It is probable that this leakage correction is too large in all three cases, owing to the assumption of no saturation except in those parts of the magnetic circuit which carry the leakage flux.

It was necessary to extend the saturation curves of machines

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2 and # 3 somewhat beyond the observed points, and this may have introduced a considerable error into the value of the excitation for full inductive load, but no appreciable error into the corresponding values of the regulation.

Whatever these errors may be they are not sufficient to modify the general comparative results.

In the case of machines # 2 and # 3 the terminal e. m. f. was taken above normal in order to make them comparable with the observed results which were taken at the same points. This means working higher up on the saturation curve and a larger percentage increase of excitation from no load to full load, but no appreciable change in the regulation.

ERRATA.

Page 155, 8th line should read —

"I_a the r. m. s." — etc.

Page 158, 4th line from bottom should read —

"pole corners *or teeth*, which resist" — etc.

Page 161, 4th line from bottom —

"yolk" should be "yoke"; also, beginning at semicolon — "assume that F at full load = 1.4 × R at full load, as determined by the application of the general diagram, see below; assume the field leakage coefficient at no load to be $\nu_o = 1.3$; then at full load the leakage flux which is proportional to F_f will be 40% greater than with the same useful flux at no load. The full load leakage coefficient will then be $\nu_f = 1 + .3 \times 1.4 = 1.42$, i. e. the flux in the field core and yoke has increased" etc., page 162, 3rd line.

Page 162, second line from bottom —

"at a given power *factor*, cos θ, figure 7."

Page 165, second line —

"$E_a = \sqrt{(225)^2 + (16.1)^2} = 226$ volts

also, center of page —

"*1600* K. W. 3 Phase Alternator.

(To be concluded.)

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EDITORIALS.

We take pleasure in announcing the election of the following Active members of the Board of Editors, from the class of 1904: — Thayer Lindsley, *Civil*; Charles Heber Fisher, *Elec.*; Granville Johnson, *Mech.*; Edgar Beach Van Winkle, *Arch.*; William Rogers Wade, *Univ.-at-large.*

Mr. J. A. Moyer has been re-elected an Associate member from the Mechanical Department, and Mr. W. D. Swan has been elected an Associate member from the Architectural Department.

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This number completes the first volume of the Journal. With it also the present Board of Editors goes out of office, giving over the control of the magazine to the nineteen hundred and four Board, with heartiest wishes that great success attend their efforts, and that they may have the same generous support from our readers that we have had.

In the Lawrence Scientific School there is nothing more deserving of the interest and the support of the undergraduates than the Engineering Societies, of which there are five. Chief among them is "The Harvard Engineering Society." This association holds formal monthly meetings usually open to the University, at which practicing engineers of established reputation and ability give papers on subjects of current interest in the engineering world. The remaining four societies arranged in the order of their size, are: the Mining Club, the Mechanical Engineering Club, the Civil Engineering Club and the Electrical Engineering Club. Meetings of these Clubs are held every three or four weeks and usually take the form of "smokers" at which engineers in active practice give short informal talks on matters of general interest. The growth of all of these clubs, since their organization ten years ago, has been rapid and their possibilities, either as valuable aids to one's work, or in a social way, are being realized more and more. The fees in any of the societies are very small and membership is open to practically all men who take engineering courses. It is certainly well worth while for every man interested in engineering to join one of these organizations.

GRADUATE NOTES.

Howard Elliott, '81, is first vice-president of the Burlington Route.

E. A. S. Clarke, '84, is general manager of the Illinois Steel Works.

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W. A. Baldwin, Jr., '85, has been appointed second in charge of the Pennsylvania R. R. Tunnel under New York City.

F. A. Delano, '85, has recently resigned his position as general manager of the Burlington Route.

R. W. Bush, '89, is engineer of the Metropolitan Gas Works of the Brooklyn Gas Company.

C. M. Saville, '89, is a division engineer of the Metropolitan Water and Sewerage Board of Massachusetts.

G. A. Campbell, '92, is an electrical engineer with the American Bell Telephone Co., Boston.

G. S. Curtis, '92, has been hydraulic engineer of the Boston Fire Department since 1899.

Charles Garrison, '92, is vice-president of the Chase-Shawmut Co.

W. Cary, '93, is vice-president of the Milwaukee Electric Co.

J. E. Spurr, '93, is consulting geologist and mining engineer to the Sultan of Turkey.

C. R. Perry, '95, is with the Boston Bridge Works.

Edward Slade, '95, is general manager of the Jaques Cartier Water Power Co., Quebec.

G. S. Parker, '00, is studying Architecture in Paris.

F. L. Jones, '02, is with the Bethlehem Steel Works.

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Moreover, when a "closed" heater becomes foul with deposited impurities, its heating capacity is seriously impaired. A "Cochrane" must be almost choked with deposits before it ceases to heat the full quantity of water. Besides, a Cochrane Heater is easily cleaned, and a closed heater isn't.

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In point of fact, however, the baffle is placed at a distance from the entry port which experience has proven to be just right. As a result, the steam strikes the baffle squarely, and, being relieved of the entrained oil, water or other liquid, which is diverted into the well by the ribbed construction of the baffle, passes around the sides and goes on its way—with no steam cushion, undue friction, back pressure or loss of velocity. Thus a baffle (the most effective separator) is used in the COCHRANE, without any of the disadvantages that commonly attend it.

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